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THE PEANUT

THE UNPREDICTABLE LEGUME

A SYMPOSIUM

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THE PEANUT—
THE UNPREDICTABLE LEGUME

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The National Fertilizer Association
and the chapter authors
take pleasure in dedicating this book
to the advancement of American Agriculture

PREFACE

THE PEANUT—THE UNPREDICTABLE LEGUME has brought together between two covers authoritative information on this crop. From a mass of data, much of which is contradictory, inconsistent and erratic, here is presented a consolidation and interpretation of present-day ideas which forms a sound foundation for further needed research on the economic production of peanuts—the most peculiar of all major farm crops. This volume is a valuable contribution to the understanding of the peanut plant and its economic production. It should not be construed as an end point to the problems in agronomy, plant nutrition, plant physiology, plant pathology, biochemistry, agricultural engineering and entomology. Many of such problems, however, are clarified by the material presented.

Generous credit is due the chapter authors upon whom the burden of preparing the subject matter fell. Years of patient work in consolidating and interpreting the results in each field of investigation are represented by THE PEANUT—THE UNPREDICTABLE LEGUME. The contributions of the chapter authors have been unselfishly made in the interest of the advancement of agricultural science. They deserve the gratitude of all producers, processors and consumers of peanuts.

The development of this volume began in 1937 when the great problems of varying results involving fertilizer field trials engaged the attention of the Plant Food Research Committee of The National Fertilizer Association. The need for more research was presented to and approved by the Southeastern Agronomy Research Committee of the Southeastern Experiment Stations, January 31, 1939. Then followed a series of conferences of research workers. These scientists contributed data and observations which stimulated new research and clarified previous findings. Annual conferences were held from 1939 to 1944, inclusive, and, after a year's omission, were resumed in 1946 and continued through 1948.

Personalities involved in the many investigations and contributing to the understanding of peanut production problems at the various conferences included many distinguished authorities.

Chairmen of the conferences during the various years were: W. E. Stokes, Florida Agricultural Experiment Station, N. J. Volk, Alabama Agricultural Experiment Station, and R. W. Cummings, North Carolina

Agricultural Experiment Station, all of whom gave generously of their time.

Financial support for the annual conferences and for the publication of this book was contributed by The National Fertilizer Association.

It would be a great injustice not to recognize the efficient work of H. R. Smalley, R. H. Lush and M. H. McVickar, all of The National Fertilizer Association, who served as secretaries of the various conferences.

Members of the Plant Food Research Committee of The National Fertilizer Association who served on the Peanut Research Committee at various times include: T. F. Bridgers, C. J. Cahill, Leroy Donald, Myron S. Hazen, G. N. Hoffer, Frank L. Holland, Wallace Macfarlane, H. B. Mann, R. D. Martenet, F. W. Parker, J. R. Taylor and the undersigned Chairman.

Respectfully submitted,

DAVID D. LONG, *Chairman*
Subcommittee Peanut Fertilization
Plant Food Research Committee
The National Fertilizer Association

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THE PEANUT—
THE UNPREDICTABLE LEGUME

CHAPTER I

ECONOMIC IMPORTANCE OF PEANUTS

By

B. B. HIGGINS[1]

The peanut is generally recognized as one of the important crop plants of the world. This recognition has arrived very slowly. Although the plant has been known to Europeans since the sixteenth century, it was only approximately 100 years ago that the oil mills of Marseilles, France, began importing and crushing peanuts grown in North Africa. This may be considered the beginning of large-scale industrial use of the crop, though an oil mill was established at Valencia, Spain, 50 years earlier (7). The desirable qualities of the peanut oil brought early success to the enterprise, and mills for crushing peanuts were quickly established in other European countries. Since then, the commerce in peanuts has expanded slowly to its present proportions. In 1947 the commercial crop of the world amounted to 10,579,000 tons.

The relative importance of the producing areas of the world is shown in table 1. While figures given for many countries are admittedly only estimates, they do indicate the relative importance of various world areas insofar as the commercial production of peanuts is concerned. They indicate that the peanut is now an important crop in the warmer areas of all six continents of the world. The world trade depends largely on the European demand for oil. India, China, Burma, Sumatra, Java, and the French African colonies have long been the principal exporters of peanuts. At present, the supply is inadequate to meet the demand. World War II so upset and confused agricultural production in Europe that there is an enormous shortage of edible fats and oils. Increased production of peanut oil appears to offer the most feasible possibility for early and permanent

[1] B. B. Higgins is botanist, Georgia Agricultural Experiment Station.

Table 1.—Peanut Acreage and Production in Specified Areas and Countries.[a] Sources of data: *Foreign Crops and Markets*, U. S. Dept. Agri. 55 (22): 371-373; 57 (22): 427-430.

Continent and Countries	Average 1935-39		Average 1943-47		Average 1943-47
	Acreage	Production	Acreage	Production	Acre Yield
	acres	tons	acres	tons	pounds
North America					
Mexico	33,000	12,200	98,333	43,750	890
United States	1,659,000	614,700	3,409,000	1,052,580	618
Cuba	—	8,400	95,800	27,200	568
Dominican Republic	—	3,800	35,400	8,180	462
Total[b]	1,800,000	640,000	3,494,000	1,136,200	650
Europe					
Bulgaria	5,000	2,200	3,400	940	553
Italy	2,000	1,600	7,600	5,320	1,400
Spain	24,000	23,300	16,333	11,433	1,400
Total[b]	35,000	28,000	33,000	20,000	1,212
Russia (Europe & Asia)	29,000	—	—	—	—
Asia					
Burma	784,000	192,200	636,250	127,050	399
China proper	3,639,000	2,913,400	3,444,000	2,614,300	1,518
Manchuria	—	121,600	—	—	—
French India	7,000	5,600	7,000	5,633	1,609
French Indo China	42,000	16,000	107,000	27,000	505
India	7,535,000	3,295,700	10,123,800	4,005,258	791
Japan proper	19,000	14,600	—	19,800	—
Formosa	77,000	57,700	—	—	—
Kwantung	101,000	91,100	—	—	—
Netherlands Indies	572,000	289,100	430,400	190,440	885
Philippine Islands	18,000	4,700	—	—	—
Total[b]	13,200,000	7,040,000	15,238,000	7,246,600	951
South America					
Argentina	207,000	87,300	330,800	154,120	932
Brazil	—	14,800	87,000	34,133	785
Paraguay	29,000	19,400	21,500	13,250	1,233
Uruguay	5,000	1,200	16,400	4,700	573
Total[b]	400,000	129,000	520,000	208,000	800
Africa					
Anglo-Egyptian Sudan	43,000	8,100	55,000	500	418
Belgian Congo	245,000	65,100	540,000	—	—
Tanganyika	277,000	23,400[c]	—	6,620[c]	—
Uganda	156,000	2,200[c]	333,333	9,550[c]	—
Gambia	—	58,100	—	84,900	—
Egypt	23,000	17,200	25,800	19,760	1,532
Fr. Equatorial Africa and Cameroun	388,000	58,800	—	—	—

Table 1—Continued

Continent and Countries	Average 1935-39		Average 1943-47		Average 1943-47
	Acreage	Production	Acreage	Production	Acre Yield
	acres	tons	acres	tons	pounds
Fr. West Africa	2,955,000	875,900	—	527,340	—
Madagascar	14,000	6,600	26,400	7,980	605
Mozambique	—	42,900[c]	—	19,525	—
Nigeria and Cameroons	—	354,700[c]	2,500,000	538,400[c]	431
Angola	18,000	6,200	—	7,267	—
Portuguese Guinea	—	28,000[c]	—	33,733	—
Union of South Africa	56,000	12,000	95,000	22,600	476
Total[b]	6,120,000	1,673,000	6,000,000	1,461,600	487
Oceana					
Australia	14,000	6,100	23,800	23,900	1,168
Total[b]	15,000	6,500	27,200	13,800	1,015
World Total	21,600,000	9,531,000	25,380,000	10,090,600	795

[a] Harvested crop statistics not complete for all years of periods covered.
[b] Continental totals include estimates for other minor producing countries.
[c] Exports only.

relief. A large government-sponsored project for increased peanut production in the Belgian Congo is already in operation; another, sponsored by the British Government, has for its objective the mechanized production of peanuts on 3 million acres in Tanganyika and Northern Rhodesia; and production in French West Africa and Nigeria is being vastly expanded.

Previous to development of the peanut oil industry, the world trade in peanuts was unimportant. However, in every country where grown, they were considered an important item of food and considerable local trade sprang up. The peanuts were most commonly roasted in the shell and sold for immediate consumption. They were also used for making candy and other confections. While a peanut paste similar to peanut butter was apparently made and used by the South American Indians, utilization of peanuts in this type of product has not reached commercial importance except in the United States. In Spain and in some Spanish-American countries, peanuts are ground, mixed with cocoa or with honey and utilized for food; but exact data as to the extent of this utilization are not available.

DEVELOPMENT OF THE PEANUT INDUSTRY IN THE UNITED STATES

"Groundnuts" are mentioned (19, 20) in some of our earliest Colonial records, but this name was used for other plants as well as for peanuts, and we are often not sure what plant was indicated. Whether or not peanuts were grown within the present limits of the United States by the Indians of pre-Columbian times is still questionable, but we do have authentic records of peanut culture during Colonial days. The following quotation from a report by Sir William Watson (27) to the Royal Society and published in the *Philosophical Transactions* for October 1769 is of special interest:

"It is with this view, that I lay before you some pods of a vegetable and the oil pressed from them. They were sent from Edenton, in North Carolina, by George Brownrigg, whose brother, Dr. Brownrigg, is a worthy member of our Society; and are the produce of a plant well known and much cultivated in the Southern colonies and in our American sugar islands, where they are called groundnuts, or ground pease. . . . Mr. Brownrigg, from whom as I before mentioned, I received the oil, considers the expressing oil from the ground pease, as a discovery of his own: It may, perhaps, at this time, be very little practiced either in North Carolina, the place of his residence, or elsewhere. But certain it is that this oil was expressed above fourscore years ago; as Sir Hans Sloane mentions it, in the first volume of his History of Jamaica; and says that this oil is as good as that of almonds. . . . After the oil has been expressed from the ground pease, they are yet excellent food for swine."

Thomas Jefferson (6) mentioned peanuts as being commonly grown in Virginia, but implied that the crop was of little importance commercially. Before the Civil War, they were grown commercially at least for local consumption throughout the South and even in California. Ramsey (23) in his history of South Carolina, 1809, mentioned among vegetables, groundnuts used as a food, as a substitute for cocoa, and as a source of oil for domestic use. In discussing Edisto-Island, he again mentioned groundnuts, saying, "They are planted in small patches chiefly by negroes for market. They produce 80 bushels per acre. They are commonly sold for five shillings sterling per bushel. . . . price in 1768 was eight pence sterling per bushel." The fact that they were being grown commercially in South Carolina is shown also from records of exports from the port of Charleston. We find a shipment of 51 casks of

groundnuts recorded (8) for the year November 1786 to November 1787. Williams (28), in discussing the agriculture of the Territory of Florida (1830) says: "The peanut produces a large crop and is a useful article in the dessert." Burke (9), in describing life on a slave-operated plantation near Savannah, Georgia, during the first half of the nineteenth century, says: "Great quantities of peanuts are raised there, not only as an article of export, but to fatten swine upon. They are planted in the same manner as potatoes and when they have come to maturity the swine are turned in upon them to dig their own food. It is not usual for planters to feed their swine in any other way. . . ."

Several others writing from Georgia (4, 23), Alabama (13), Mississippi (22), Louisiana (17) and California (5) at about this date spoke of peanuts as a valuable crop, especially for hog feed. In 1851, W. B. Easby (15) of Vernon, Tennessee, wrote: "The goober pea is extensively raised here, and so far has proved the most profitable crop that can be raised. The first ever raised for market was sold in Nashville in the fall of 1845. Since that time there has been upwards of 20,000 to 25,000 bushels raised within 10 to 15 miles of this place each year, and sell for 65 cents to one dollar per 22 pounds. The vine is equal to clover hay for stock, if well saved."

During and after the Civil War commercial production increased rapidly. Exact statistical records for the period are not available, but in the *Annual Report* of the U. S. Department of Agriculture for 1868 is found a 4-page discussion of the crop. It is stated that the Virginia crop for that year was estimated at 300,000 bushels, selling at $2.75 a bushel (22 pounds). Two varieties are mentioned: Virginia and the Carolina or African.

At this time most of the commercial crop was roasted in the shell and sold freshly roasted by street vendors. The work of harvesting, picking and preparing for market was all done by hand or with crude homemade equipment. Lack of commercial shellers undoubtedly retarded utilization of peanuts. Lack of uniformity and poor quality discouraged trade in peanuts even for roasting. Some farmers built crude equipment for scrubbing and shaking dirt from the peanuts and blowing out trash and "pops," and hand-picked the discolored nuts; but this practice for improving the uniformity and quality of the product was not general. In 1870, P. D. Gwaltney (7) began buying peanuts from growers about Smithfield, Virginia, cleaning them as best he could with such crude equipment as available, and reselling. Ten years later, he, in partnership with A. Bunkley, built what is said to have been the first factory for

cleaning, grading, and polishing peanuts to be roasted in the shell. Apparently, however, another factory was built in New York City about the same date (21), probably for cleaning imported stock.

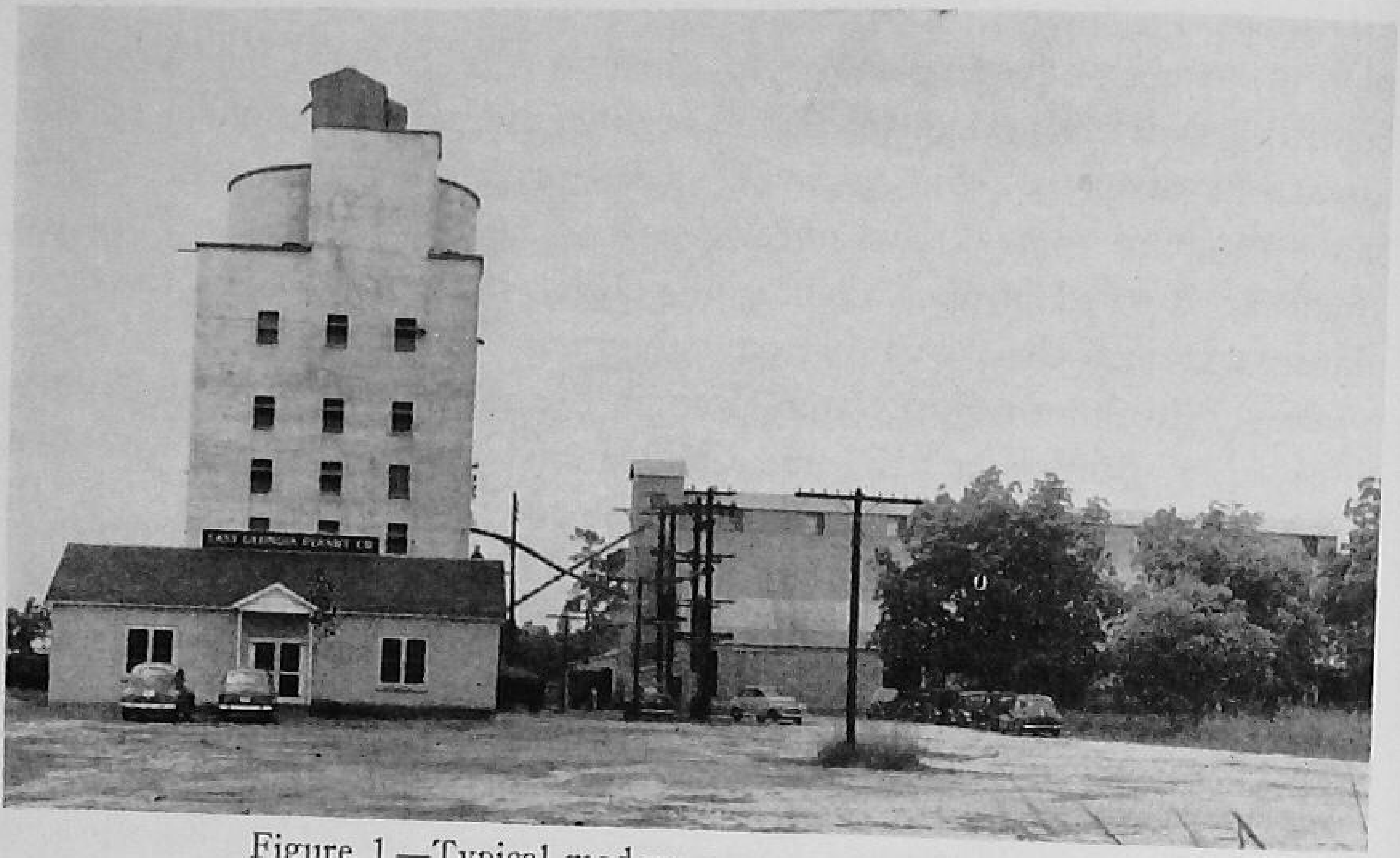

Figure 1.—Typical modern peanut processing plant.

More important for development of the peanut industry was the invention and manufacture of machinery for planting, cultivating and harvesting the plant, picking the nuts from the plants, and for shelling and cleaning the seed. Without these labor-saving machines, peanut production would undoubtedly have declined with the gradual increase in cost of human labor. In 1872, H. E. Colton (12) writing about peanuts, said that under stress of producing peanuts for oil during the Civil War, a mechanic, Thomas L. Colville of Wilmington, North Carolina, built machines for threshing the nuts from the vines and winnowing them and also built machines for removing the shells. Neither machine was patented and many variations and improvements were tried before a really satisfactory picker was built about the beginning of the present century. Development of a successful planter, of the scraper plow, the weeder, and the peanut wing for cutting the roots in harvesting, are among the important inventions that materially reduced the labor of producing peanuts and led to vast expansion of the peanut industry during the present century. The mechanical sheller has been an especially important factor in increasing the use of peanuts and peanut products such as peanut oil, roasted and salted nuts, peanut butter, peanut candy, and other confections.

Apparently pre-Columbian Indians of America (14) and the African natives (11) made and used both peanut oil and a peanut paste comparable with our peanut butter long before the white man used either product. Apparently, peanut butter was first made commercially about 1890 by a physician (25) in St. Louis, Missouri, who prescribed it for some of his patients as a nutritious, easily digested, high-protein food, low in carbohydrates. The idea spread rapidly. Winton (29), in 1899, published analyses of two brands; and in 1914, Utt (26) analyzed and examined for adulterants 23 brands bought on the markets of Kansas City. At present, more than half the peanuts shelled for the edible trade go into the production of peanut butter.

The increased need for oil for various uses in time of war has caused great expansion of peanut production during each such period since 1860, and other uses have usually absorbed the increase in each subsequent period. Several writers agree that rapid expansion occurred between 1860 and 1870. Again referring to the article by Colton (12), published in 1872, we read: "Instead of 1,000 there are fully 550,000 bushels sold annually in the city of New York alone. Previous to 1860, the total production of the United States did not amount to more than 150,000 bushels, and of this total fully five-sixths were from North Carolina. Now, North Carolina produces 125,000 bushels; Virginia, 300,000 bushels; Tennessee, 50,000 bushels; Georgia and South Carolina, each, 25,000 bushels; while from Africa come about 100,000 bushels a year." We may feel inclined to doubt Colton's data, but his estimates as to the size and the distribution of the industry cover a period for which we have no authentic records. It seems probable that the estimates were based on only that portion of the crop which entered interstate commerce, since statistics on crop acreage in Georgia, furnished by the Comptroller General to the Georgia Agricultural Society (6), gave for the peanut crop 16,619 acres in 1873 and 21,162 acres in 1874, several times the acreage necessary to produce 25,000 bushels.

Acreage and production of peanuts are recorded in the Eleventh *Census Report* for the year 1889, and are included in all subsequent enumerations. The U. S. Department of Agriculture, through its system of crop estimates, has kept fairly accurate annual records of total acreage planted, acreage harvested, and the production by States. During the period of acreage limitation, from 1934 to 1942, more exact data were obtained as to the harvested acreage and production.

In order to facilitate marketing the crop, three producing areas have been designated: The Virginia-Carolina area, including Virginia, North

Carolina, and Tennessee; the Southeastern area, including South Carolina, Georgia, Florida, Alabama and Mississippi; and the Southwestern area, including Louisiana, Arkansas, Texas, Oklahoma and New Mexico (figure 2). The division into these three areas is based somewhat upon the type of peanut grown. The Virginia-Carolina area produces the Virginia-type peanut almost exclusively, while it is, at present, of minor importance in the other two areas. In the Southeastern area, the small Spanish type constitutes the major portion of the commercial crop. A small seeded runner of the African type is grown under several varietal names and enters the trade as "Southeastern Runner." The Virginia-type peanut is grown in Bulloch County, Georgia, and to a less extent in a few other localities. In the Southwestern area, the commercial crop is almost exclusively of the Spanish type, though a small acreage of Tennessee Red is grown in New Mexico. See table 2 for varietal distribution.

Data in table 3 show something of the development of peanut production for the country as a whole and for the seven States that account for about 90 percent of the total tonnage of the country. It is of interest to note the slight increase of acreage in Virginia and North Carolina during the World War II period in contrast with the enormous expansion in certain States of the Southeastern and Southwestern areas. This is probably due to the restricted adaptability of the Virginia type in contrast with the more widely adapted Spanish; and also to concentration of peanut acreage. Over the past 20 years the planted acreage has surpassed that harvested by about a million acres: Georgia, 400,000 to 600,000 acres; Florida, 150,000 to 300,000; and Alabama, about the same as Florida, with scattered acreage in most other States of the South, grown specifically for hog grazing.

According to the 1890 *Census Report*, some acreage of peanuts was grown in 34 States the previous year, and some acreage was reported from practically every county of the Cotton Belt. In the 1945 Census of Agriculture, some acreage was reported in 32 States. The distribution of this acreage, shown in figure 2, indicates all States in which 1,000 or more acres were reported. In most of the 32 States plantings consisted of small plots for home use only.

One can only guess as to how the peanut industry would have developed under the system of free competition prevalent prior to 1933. At that time the policy of government guarantee of a base price, in consideration of acreage limitation by growers of major farm crops, caused a slight decrease in acreage; but this decrease had been overcome by 1939. During the war years the abnormal demand for food by our own armed

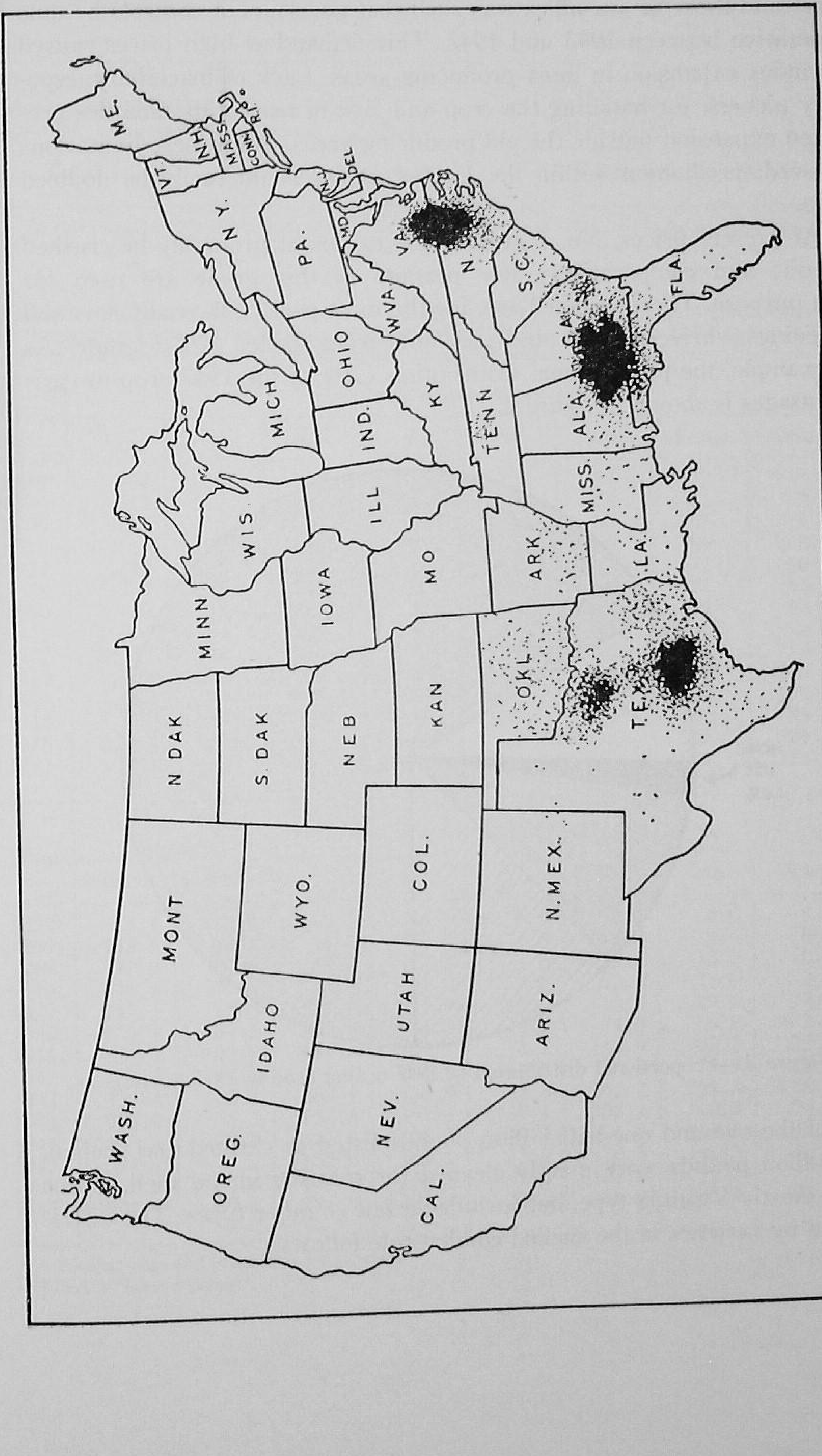

Figure 2.—Distribution, by States, of peanut production acreage in 1944. Each dot represents 1,000 acres.

forces and those of our allies was such that government controls became inoperative between 1943 and 1947. This demand at high prices caused enormous expansion in most producing areas. Lack of machinery, especially pickers, for handling the crop and lack of marketing facilities prevented expansion outside the old producing areas. With these limitations removed, production within the United States could easily be doubled again.

At present prices, No. 1 grade peanuts cannot profitably be crushed for oil; and comparatively few peanuts of this grade are used for such purpose. Those crushed are, for the most part, "off-grade" lots and screenings, shrivels, splits and pick-outs from shelled No. 1 grade. As an example, the proportional distribution (29) of the 1947 crop to various usages is shown in figure 3.

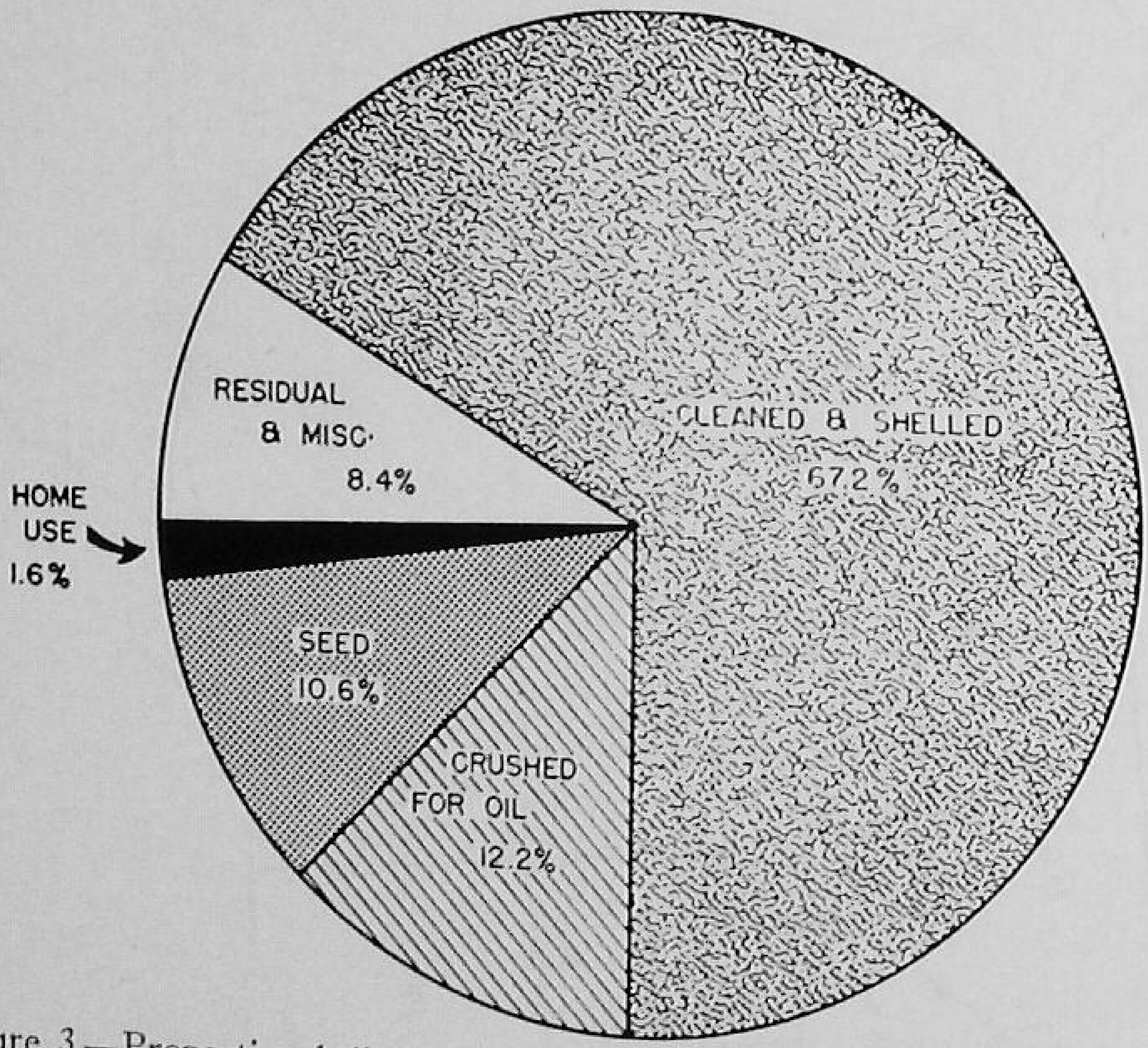

Figure 3.—Proportional distribution of 1947 peanut crop to various usages.

Of the one and one-half billion pounds listed as cleaned and shelled, 80 million pounds were merely cleaned for roasting in the shell. These were mostly Virginia-type, but included a few of other types. The distribution by varieties in the shelled edible trade follows:

Table 2.—DISTRIBUTION BY VARIETIES IN THE SHELLED EDIBLE TRADE

	Pounds	*Percent*
Virginias	174,131,000	22.6
Southeastern Runner	193,904,000	25.2
Spanish	401,224,000	52.2
Total	769,259,000	100.0

Of this total, 189,683,000 pounds were exported, leaving 579,576,000 pounds for domestic use.

Table 3.—ACREAGE AND PRODUCTION IN THE UNITED STATES AND IN EACH OF THE PRINCIPAL PRODUCING STATES FOR SPECIFIED YEARS BETWEEN 1889 AND 1947.

Year	*Acreage Harvested (000 acres)*							
	U.S.	*Va.*	*N.C.*	*Ga.*	*Fla.*	*Ala.*	*Texas*	*Okla.*
1889[a]	204	59	18	52	26	24	2	[b]
1899[a]	517	117	96	100	69	79	11	2
1909	537	145	180	45	15	60	48	1
1919	919	133	126	201	55	300	90	8
1929	1,269	153	220	375	51	213	142	50
1939	1,787	148	245	670	85	300	322	53
1940	2,052	158	257	730	90	310	335	82
1941	1,900	134	229	650	85	315	340	72
1942	3,362	148	270	1,060	115	516	870	218
1943	3,492	150	300	1,127	110	574	850	200
1944	3,068	154	295	1,050	100	520	680	178
1945	3,160	159	320	1,070	100	487	750	185
1946	3,142	150	295	1,070	95	472	767	221
1947	3,389	162	292	1,092	105	452	877	325

Year	*Production, Harvested Nuts (000 tons)*							
	U.S.	*Va.*	*N.C.*	*Ga.*	*Fla.*	*Ala.*	*Texas*	*Okla.*
1889[a]	43.1	12.9	5.1	8.7	5.0	3.9	0.6	—
1899[a]	143.6	40.8	41.5	20.1	13.6	14.3	2.6	0.7
1909	177.0	49.3	60.8	15.8	4.9	19.5	13.2	0.4
1919	344.1	70.4	70.8	57.8	18.6	82.5	25.9	2.8
1929	449.1	78.8	112.2	121.9	16.0	58.6	29.8	12.5
1939	606.1	89.5	195.8	184.3	18.7	71.3	66.8	2.0
1940	883.3	107.8	183.8	301.1	34.2	113.9	97.2	22.6
1941	737.6	84.8	137.4	234.8	28.9	126.0	79.9	18.9
1942	1,096.4	85.1	169.4	333.9	32.8	167.7	208.8	60.0
1943	1,088.3	85.5	153.8	394.5	37.4	208.1	140.3	26.0
1944	1,040.4	90.9	177.0	304.4	31.3	166.4	153.0	42.3
1945	1,021.1	74.7	152.0	361.1	33.0	170.5	161.3	43.9
1946	1,019.2	95.6	136.4	358.5	27.8	129.8	197.8	58.6
1947	1,094.0	99.6	171.6	390.4	32.8	146.9	186.4	75.6

[a] Total acreage and production for all areas
[b] Only 17 acres reported

The per-capita consumption of peanuts has just about doubled during the past 20 years, and now amounts to more than 10 pounds per person. Most of this increase has occurred since 1939 and is doubtless due in some measure to extensive use by the armed forces during the war period, though civilian use increased during the same period because of scarcity of meat. However, during this same period an intensive advertising campaign was carried on, stressing the food value of peanuts. This campaign doubtless had considerable influence. An example of the information used in this campaign is shown in table 4, where the nutritive value of

Table 4.—NUTRITIVE VALUE OF ONE POUND OF SELECTED FOODS AS PURCHASED.

Item	Unit	Peanut butter	Roasted in shell	Beans common or kidney[a]	Beans lima[a]	Beef		Pork
						Rib roast rolled	Round steak	Fresh ham
Refuse	Percent	0	28	0	0	0	11	14
Food energy	Calories	2,808	1,961	1,588	1,548	1,252	789	1,326
Protein	Grams	118.5	88.0	99.9	94.0	79.0	78.0	59.3
Fat	Grams	217.0	144.5	6.8	5.9	104	53	121
Carbohydrates	Grams	95.3	77.2	281.9	279.7	0	0	0
Calcium	Milligrams	336	242	672	301	45	44	35
Phosphorus	Milligrams	1,784	1,285	2,102	1,730	854	840	640
Iron	Milligrams	8.6	6.2	46.8	34.0	11.8	11.7	9.0
Vitamin A value	I.U.	0	0	0	0	0	0	0
Thiamin	Milligrams	.89	.96	2.71	2.71	.49	.48	3.75
Riboflavin	Milligrams	.72	.52	1.07	1.07	1.07	.62	.73
Niacin	Milligrams	73.5	53.0	9.6	9.6	21.3	21.0	16.0
Ascorbic Acid	Milligrams	0	0	8	8	0	0	0

[a] Dry seed.

peanuts is compared with that of four other common foods (8). Continued publication of such information can be expected to have a decided influence upon the demand for peanuts and encourages the hope that the per-capita consumption of peanuts and peanut products may continue to increase rather than recede to the former level.

Much money and effort have been expended upon development of new ways of introducing peanuts into the diet, utilizing the whole peanut or the defatted peanut flour; but none of these new items has yet become important commercially. The important channels for disappearance of the edible peanut stocks are shown in figure 4.

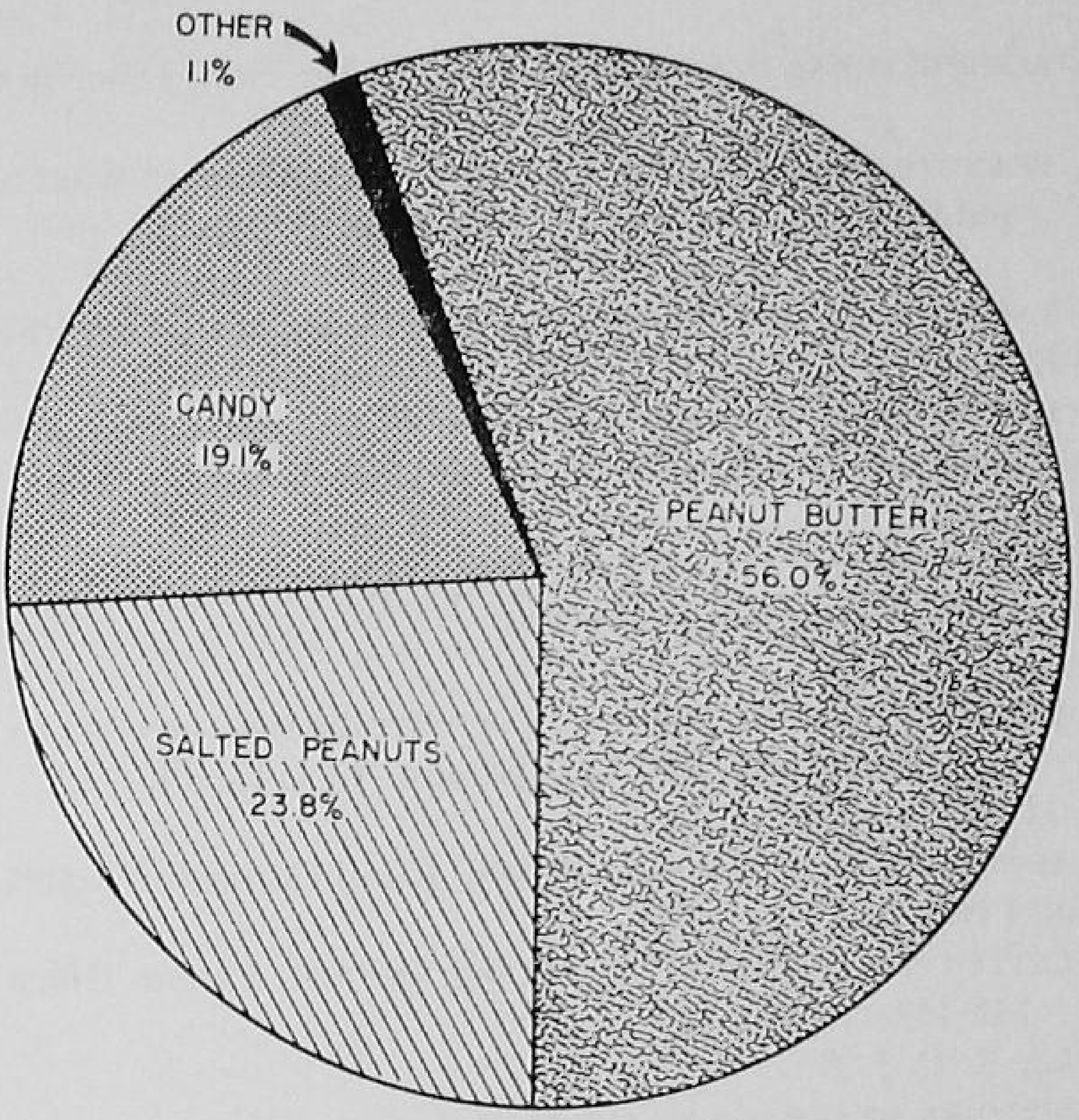

Figure 4.—Important uses of edible peanut stocks.

Peanut butter now accounts for disappearance of more than 50 percent of our edible stock. Of the 1947 crop, nearly 325 million pounds were utilized in peanut butter. This was 56 percent of the shelled edible stock retained for domestic use. At present considerable research is being directed toward improving the quality of peanut butter, and there are indications that consumption will continue to increase.

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CHAPTER II

ORIGIN AND EARLY HISTORY OF THE PEANUT

By

B. B. HIGGINS[1]

What are the origin and the history of the cultivated peanut, and what are its close relatives in the plant world? One would think that a plant with such striking botanical characteristics and with such economic possibilities could not long escape notice of botanists or of those interested in production of food crops, and that these questions would be readily answerable. However, the New World presented to the eyes of explorers and colonists so many new plants: Indian corn, Irish potato, sweet potato, cassava, cacao, beans, tobacco and many other plants of even greater interest that the peanut received scant attention. Consequently, the origin, history, introduction into various countries, and the affinities of the cultivated peanut are still hazy. Many points have been cleared during the past 25 years and with the accelerated investigations now in progress much more information should be available within a decade.

In 1933, August Chevalier (6) wrote, *"le probleme de le origine de l'Arachide a fait couler des flots d'encre."* (Translation: The problem of the origin of the peanut has made floods of ink flow.) During the nineteenth century a number of authors attempted to prove that the peanut originated in Africa and cited plants with subterranean fruits described by Theophrastus and Pliny as occurring in Egypt and other Mediterranean countries. Chevalier (6) has summarized the opinions of various students as to the identity of these plants and the evidence is conclusive that neither Pliny nor Theophrastus saw or mentioned the plant now known as *Arachis hypogaea*. The Arachidna of the ancient Greeks was evidently applied to a species of *Lathyrus*, Arakos referred to *Lathyrus tuberosa*, the Ouiggon mentioned by Theophrastus as occurring in Egypt was

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Calocassia antiquorum, and the Oetium of Pliny referred to *Cyperus esculentus. Arachis hypogaea* was introduced into Egypt only in recent times as indicated by the vernacular name "ful sudani." The confusion was accentuated by the fact that the name Arachidna was used for the peanut by several naturalists and voyagers near the close of the seventeenth century.

Likewise, there is nothing to support the suggestion of Asiatic origin. Tradition in China and in India indicates recent introduction into the Asiatic mainland from the Philippine Islands or other of the South Pacific Islands.

Many attempts have been made to trace the distribution of the peanut through the vernacular names which might have been passed from one locality to another with seed of the plant. Chevalier (7) lists several hundred but, with few exceptions, these are local names which in that dialect are more or less descriptive of the seed or fruits of the plant as, for example, the English names, peanut, groundnut, and groundpea; the French, "*pistach du terre,*" (*ground pistache*); and the Portuguese, "Amendoim." Exceptions to be cited such as "pindar" and "goober" are undoubtedly corruptions from some African names by African-born slaves who had known either the peanut or Voandzeia in Africa. The two common names in use in Spanish-speaking countries are: "Cacahuate," used in Spain and Mexico, derived from the Nahuatlan (Aztec) name "tlalcacahuatl" (earth cacao); and the other, "mani" used throughout Spanish America except Mexico, is Thalail name heard by the Spaniards in Hispanola, now Haiti-Santo Domingo. The Brazilian name "Mandubi" is apparently derived from the Indian name which is variously written from the Indian articulation as "Mandobi," "Manobi," "Mun dubi," "Mondorvi" and "Minui."

In 1838, Bentham published his "Flora Braziliensis" describing five species of *Arachis*, all from Brazil. This caused botanists generally to take with favor the claim for American origin of the cultivated *A. hypogaea L.* because, as stated by A. de Candolle (4), "A genus with all its known species thus confined to a single region of America can hardly have a species common to both the New World and the Old. That would be too great an exception to a common principle of phytogeography." But positive proof as to American origin came with the discovery of peanuts, similar in appearance to varieties now grown in Peru, in ancient graves excavated at Ancon, Pachacamac, and other points in the desert region along the coast of Peru, about 1875. E. G. Squier (21), a United States Commissioner to Peru, gives a vivid description of these burial grounds:

"During my residence in Lima, I visited the ruins of Pachacamac, twenty miles south of the capital. . . . Pachacamac is one of the most notable spots in Peru, for here, as we are told by the old chroniclers, was the sacred city of the natives of the coast before their conquest by the Incas. . . . In Pachacamac, the ground around the temple seems to have been a vast cemetery. Dig almost anywhere in the dry nitrous sand, you will come upon what are loosely called mummies, but which are the desiccated bodies of the ancient dead. . . . I will record what I found in a single tomb, which will illustrate how a family, not rich, nor yet the poorest, lived in Pachacamac. . . . Besides the bodies there were a number of utensils, and other articles in the vault; among them half a dozen earthen jars, pans and pots of various sizes and ordinary form. One or two were still incrusted with the soot of the fires over which they had been used. Every one contained something. One was filled with groundnuts familiar to us as peanuts." Since the coast tribes occupied this region before development of the Incan Empire, some archaeologists consider these graves as possibly antedating our Christian era, but overlapping of the various culture periods of the area makes dating of the graves uncertain. There can, however, be no doubt that they are very ancient, certainly pre-Columbian.

Monardes (16), who lived in Peru about 1550, described briefly the subterranean fruits without giving a name for the plant. He said it was grown along the Maranon River and was highly esteemed by both Indians and Spaniards.

Garcillosa de la Vega, son of an Incan princess and a Spanish father and born in Peru in 1539, published in 1609 his "Los Commentaries Reales" in which mention is made of "ynchic" as an important food of the Incas.

Thus, Peru has become conspicuously associated with the peanut, and development of the cultivated forms is frequently cited as one of the accomplishments of the Incas; but continued study of old manuscripts has shown that cultivation of the peanut was by no means confined to Peru and Brazil at the time Columbus visited the New World. It is of interest in this connection to remember that the two common names for the plant in Spanish-speaking countries, "mani" and "cacahuate," are of North American origin.

Las Casas (5), a priest who lived in "New Spain" (now Haiti-Santo Domingo) from 1510-1530, mentioned "mani" among the food plants being grown by a tribe of Indians on the island. Likewise Oviedo (17), the official historian of "New Spain" 1513-1524, mentioned "mani" as

one of the important food plants very commonly grown by the Indians of "New Spain" and other islands of the West Indies. The complete record follows: "Del mani, que es cierto genero de fructa e mantenimiento ordinario que tienen los indios en esta Isla Espanola e otras islas destas Indias.

"Una fructa que tienen los indios en esta Isla Espanola, que llamen *mani,* la qual ellos siembran, e cogen, e les es muy ordinaria planta en sus huertos y heredades, y es tamana como pinones con cascara, e tienenla ellos por sana: los chripstianos poco caso hacen della, si no son algunos hombres baxos, o muchachos y eschlavos, o gente que no perdona su gusto a cosa alguna. Es de mediocre sabor e de poca substancia e muy ordinaria legumbre a los indios, e hayla en gran cantidad." (Translation: "Of the peanut, which is a certain kind of fruit in common use by the Indians in this Isla Espanola and other islands of the Indies. A fruit which the Indians in this Isla Espanola have, they call *mani* (peanut) and they plant it, and harvest it and it is a common plant in their gardens and fields, and it is the size of a pine nut with a shell, and they think it is healthful; the Christians pay little attention to it, unless they are common people, or children, or slaves, or people who do not have a fine taste. It is of mediocre taste, and little substance, and is a very common food of the Indians who use it in quantity.")

About the same time (1518-1521) Cortes conquered Mexico and this was quickly followed by exploration and colonization. Many voluminous reports on the natural resources of the country and on the Aztec civilization and customs were sent to the king of Spain. Few of these early documents have been available for study and no clear-cut picture of the culture and use of peanuts by the Indians of Mexico has been obtained. In reporting on medical practice among the Aztecs, Sahagun (19), historian and instructor in a mission school at Tlatalalco, 1529-1590, mentioned use of *tlalcacauatl* (Nahuatlan name for peanut, from *tlatle* = earth and *cacauatl* = cacao seed) as a poultice for swollen gums; but he did not list it under this name among the plants used for food.

Jean de Leary (15), who lived at Rio de Janeiro about 1555, published a description of the fruits under the Brazilian Indian name "manobi." According to Filcalho (11), it was again noted in Brazil in 1570 by Gabriel Soares de Souza, and again in Peru about the same time (1571) by Joseph de Acosta (1).

During the next 200 years the plant was described or mentioned by many botanists and explorers in the New World, and by botanists in Europe; but it was not until about 100 years ago that the range of the

wild species began to be extended beyond the borders of Brazil. Since then the wild species have been found abundantly distributed from the Amazon River through Brazil, Bolivia, Paraguay, Uruguay and northern Argentina to about 35° south latitude. The wild species of *Arachis* form an important part of the herbage for supporting the vast herds of cattle in this region. Some species seem especially adapted to growth and survival in hard clay soils and under conditions of close grazing. Others occur mostly in loose-textured sandy or alluvial soil. The cultivated forms are even more widely distributed and appear to be especially numerous and diverse in northern Argentina. E. C. Clos (9), in 1939, published on the types of cultivated peanuts, apparently indigenous to Argentina. He assembled 46 collections, including those grown commercially as well as those grown by various groups of Indians. These were grown and grouped according to characteristics such as: Vine type, bunch or runner; pod size and shape; size and number of seed; and color of seed coat, black, red, flesh, white, and white with red splotches. The 46 strains appeared to be quite homogenous and fell into 15 distinct classes.

There is considerable evidence indicating that the cultivated forms of the peanut originated in the Gran Chaco area including the valleys of the Paraguay and Parana rivers, and were at an early date distributed throughout the tropical and subtropical regions of both South and North America.

The various Indian tribes were not so isolated as one might suppose. In this connection, it is of interest to remember the Incan legend that they came to Peru from the South; also that the Incan Empire included a part of northern Argentina well east of the Andes. Archaeologists and ethnologists are convinced that a great influx of South American Indians came to Central America in a pre-Maya era. Central American Indians told the Spaniards of the fabulously wealthy Incas in Peru and of the great cities of the Aztecs in Mexico. Apparently there were regular trade routes between the Aztecs and the pueblo-dwelling tribes in what is now New Mexico. Archaeologists (13) also find evidence of communication between the Indians of the West Indies and those of the entire Gulf Coast.

It is not unbelievable, therefore, that the peanut was carried by the Indians to most areas suited to its culture, just as they spread corn, bean, pumpkin, cassava, sweet potato, and Irish potato.

How can we account for rapid establishment of peanut culture in other portions of the world, particularly in Africa and in Asia?

Chevalier (6) reviewed the argument of Brown, Ficalho, and Wiener

supporting the contention that *Arachis hypogaea* was indigenous in Africa, and concluded that there is absolutely no proof of the presence of this plant in Africa in pre-Columbian times. Continuing, he says that after 1502 communication between the west coast of Africa and Brazil was frequent. Portuguese ships going to Brazil always touched the African coast to take on fresh water and food, and the return trip was made by the same route. Naturally, having established colonies and trading posts on both coasts, the products of each were introduced to the other country. They introduced the African *Voandzeia subterranea* into Brazil where it was grown to some extent under the name "Mandubi de Angola." Pedro Alvares Calval, sailing for India with a large fleet, swung too far west and touched the Brazilian coast on April 22, 1500. He took possession of the land in the name of Portugal, then sailed on around the Cape of Good Hope to the East Indies. After this time, the Portuguese were very active in exploration and establishment of trading posts in Brazil, in Africa, and in the East Indies. Apparently they introduced maize, cassava, tobacco, and peanuts to the coasts of Africa. All four spread so rapidly that travelers in Africa a hundred years later thought all indigenous to Africa. It seems likely that the Portuguese introduced the plants at many points along the African coast, since they had already established small colonies and trading posts even along the east coast of Africa prior to 1522, when Juan Sebastian del Cano, in command of the "Vittoria" in the final lap of Magellan's voyage around the world, feared to put in at any point along the African coast, although many men of his crew were dying of starvation; because he feared interception by Portuguese.

Both Portuguese and Spaniards probably carried peanuts to the East Indies during the early years of the sixteenth century. Waldron (23) and others have suggested that the peanut was carried to the Philippines and the Moluccas by Magellan on his circumnavigation trip, but this seems hardly probable. According to Pigafetta's (18) account, Magellan's fleet wintered at Port St. Julian, southern Patagonia, and the following spring passed through the Strait of Magellan and then sailed west-northwest for 3 months and 20 days without seeing land. He did not touch Peru as suggested by Badami (3). Since his crew was reduced to eating rats, sawdust, and leather from the ship's rigging, they certainly would have eaten any peanuts that were aboard. Furthermore, Pigafetta does not mention any seed or any agricultural products among the articles traded or presented to the islanders. He did mention that Chinese trading vessels visited the islands during Magellan's stay. After Spanish colonization of

the Philippine Islands, the islands were governed from Mexico and a regular trade route was established between them and the west coast of Mexico, and it would seem likely that peanuts were carried there from Mexico.

The statement that the peanut was not known in North America until introduced on slave ships from Africa has been made so frequently that we have accepted it as true, in spite of the evidence that it was being grown in Mexico and Central America (12, 19, 23) as well as in various islands of the West Indies before the arrival of Europeans. This statement was based upon a single paragraph in which Hans Sloane (20), in his natural history of Jamaica, mentioned peanuts grown by Mr. Harrison from "Guinea seed" and ignores the fact that he mentioned other collections. The first reference to the plant is in Volume I, pages 72 and 73, under the paragraph heading: "Arachidna Indiae utriusquetetraphylla Par. Bot. pr. p. 314." Then follows the synonomy with 36 references and ends with the statement: "In Caribearum Insularum una hanc plantam collegi, sed qua non memini." (Translation: I collected this plant on one of the Islands of the Caribbean, but which (one) I do not remember.)

On page 184 we find the commonly noted reference: "XXII. Arachidna Indiae utriusquetetraphylla. Par. Bot. pr. cat. p. 72. Mandobi fructus pisonis Mus. Swammerd. p. 15. An Terfez. Ogilb, Africa p. 22. I found this planted from *Guinea* seed, by Mr. Harrison, in his Garden in Liguanee. The fruit, which are called by seamen earthnuts, are brought from Guinea in Negro ships, to feed the Negroes withal in their voyage from Guinea to Jamaica. . . . An oil is drawn out of them by expression, as good as that of almonds. . . . This is the nut Clusius speaks of, wherewith the Portuguese victual their slaves to be carried from St. Thome to Lisbon."

Reference is also made in Volume II, page 369: "Mandubi quadrifolium Americanum fructus subterraneous flore luteo Amenduinas Lusitanorum. Surian. An Junsa Linchot. cap. 8, or cap 6, C.B. Pin. 346? Arachidna quadrifolia vellosa flore luteo. Plum. pl. Amer. p. 49. Pastaches des Isles, autrement Manobi Labat. T. 4 p. 49. Mr. Barham says, in his observations, they are eaten raw, roasted, or boiled and never occasion any headache."

There are other incidental references, but each of these three notes evidently refers to different collections and indicates clearly that peanuts were commonly grown in the islands visited by Sloane, and probably of more than one type. It seems probable that he mentioned the peanut

grown by Mr. Harrison from "Guinea seed" because it differed from those commonly found in the Caribbean Islands.

Du Tertre (10) gave a very good description of the peanut plants so that one can easily recognize the runner type, pods with two or three seed with red seedcoats. This same type of peanut was also observed by Labat (14) and described as apparently a wild plant on Guadeloupe in 1697.

Apparently the Indians of the West Indies and those of the Florida mainland had occasional contacts and in this way the Florida Indians probably obtained the peanut. However, proof of the pre-Columbian presence of peanuts in either Florida or the Texas-New Mexico area has not yet been found.

The records found to date are not clear as to the origin of the various types grown in the United States. Several authors mentioned importation, for the New York market, of peanuts from Africa; and the small-seeded runner, known successively as African, Wilmington Runner, North Carolina Runner, Georgia Runner, Southeastern Runner, etc., very probably came from Africa. The Spanish variety was imported from Spain in 1871 (2). Valencia was probably received from the same source. The origins of the Virginia type, the Tennessee Red, and the Tennessee White are still uncertain. The two latter resemble closely the peanuts most commonly grown in Mexico and Central America. Chevalier (8) described *A. hypogaea L.* var. *macrocarpa* A. Chev. to include Jumbo, Virginia Runner, Virginia Bunch and Samatiga, with Jumbo as the type. He states further that Jumbo originated at Bahia, Brazil, but failed to indicate the authority for this statement. Jumbo, as known in the United States, is not a variety distinguishable from Virginia Runner and Virginia Bunch. It should be thought of as a large-seeded strain of either Virginia Runner or Virginia Bunch and considered as a market classification rather than a variety of peanuts.

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CHAPTER III

MORPHOLOGY, GENETICS AND BREEDING

By

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JOHN A. YARBROUGH[1]

Beginning with Oviedo's (47) account of the West Indies published in 1535 and Schmidel's (64) description of his travels in the La Plata Basin during the years 1534 to 1554, the reader of the peanut literature is confronted with works in Japanese, Chinese, Dutch, Danish, German, French, Bulgarian, Russian, Italian, Spanish, Portugese, and English. Here and there, keen observers have recorded their findings regarding the structure and development of the peanut plant, only to have them buried in the passage of time by an accumulation of inaccuracy and trivia. These inaccuracies have been doubly impressed upon the writers who find that the 77 titles listed at the end of this chapter omit little indeed of the information contained in the 700-800 references at their disposal.

Prior to 1949 we have found only a single description (which was wrong!) of the morphology and development of the seed and seedling, only two inadequate descriptions of the internal reproductive morphology of the peanut, and only a few correct accounts of the relationship between the aerial flower and the subterranean fruit. In 1569 Monardes (45) was so confused by the subterranean occurrence of peanut fruits that he failed to associate these with the plant at all! A century later Marggraf (43) illustrated the fruits as growing *on the roots!* The first accurate description of the peanut flower was published by Poiteau (52) in 1806 and confirmed by Richard in 1823 (58), but Bentham's (10) erroneous

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interpretations of 1839 are still to be found in many recent textbooks.

Beginning with a consideration of the peanut seed and seedling and passing to the mature root, stem and leaf, this chapter then deals with the reproductive morphology of the plant and concludes with a discussion of its genetics and breeding. Without attempting to cite all the known references which have some bearing on the topics discussed, the writers have attempted to cover the topics themselves with as much thoroughness as existing knowledge permits. This chapter does not in any sense represent a botanical or genetic monograph on the genus *Arachis* but does summarize botanical and genetic information as it relates to a single species of the genus. It is our purpose to present the status of knowledge on peanut morphology, reproduction, variation, and breeding.

SEED AND SEEDLING

Outstanding features of the seeds of cultivated peanuts are their variable sizes, colors, and shapes. They may be red, white, purple, pink, flesh, rose, tan, light brown, or even red and white. The actual range of seed size in peanuts is probably unknown, but we have seen and planted seed ranging from 0.2 of a gram to 10 times that size. Seeds may be almost spherical, elliptical or much elongated.

Each seed is composed of two massive seed leaves (cotyledons), upper stem axis and young foliage leaves (epicotyl), and lower stem axis and primary root (radicle). A thin papery seed coat covers the seed (figure 1). In contrast to most papilionaceous legumes the axis of the embryo proper is straight. All of the leaves and above-ground parts which the seedling will have for the first 2 to 3 weeks of growth are already present in the dormant seed. The epicotyl consists of three buds, one terminal and two cotyledonary laterals. In the terminal bud there are four foliage leaves and in the cotyledonary laterals one or two leaves. Thus the dormant embryo has from six to eight differentiated leaves, all of them ready to expand and go to work immediately upon germination (76).

When peanut seeds are put to germinate at 80°F. the radicle appears after 24-36 hours. Reporting from Senegal, Bouffil (13) stated that hardly 2 days elapse before the appearance of the radicle. In Germany Richter (59) found that 8 to 10 days were required for germination in damp sphagnum in the hothouse. In outdoor plots at Raleigh, North Carolina, 8 to 10 days were required for emergence. Discrepancy between the appearance of the young root (24 to 48 hours) and the appearance of the shoot (8 to 10 days) is caused by a striking difference in

the initial growth between shoot and root. The root grows very rapidly, reaching a mean length of 46 mm. in 4 days (Bouffil, 13) and 100 to 400 mm. in 4 to 5 days (Yarbrough, 76). During the first 2 days of this rapid root growth no lateral roots develop (figure 2). But by the time the

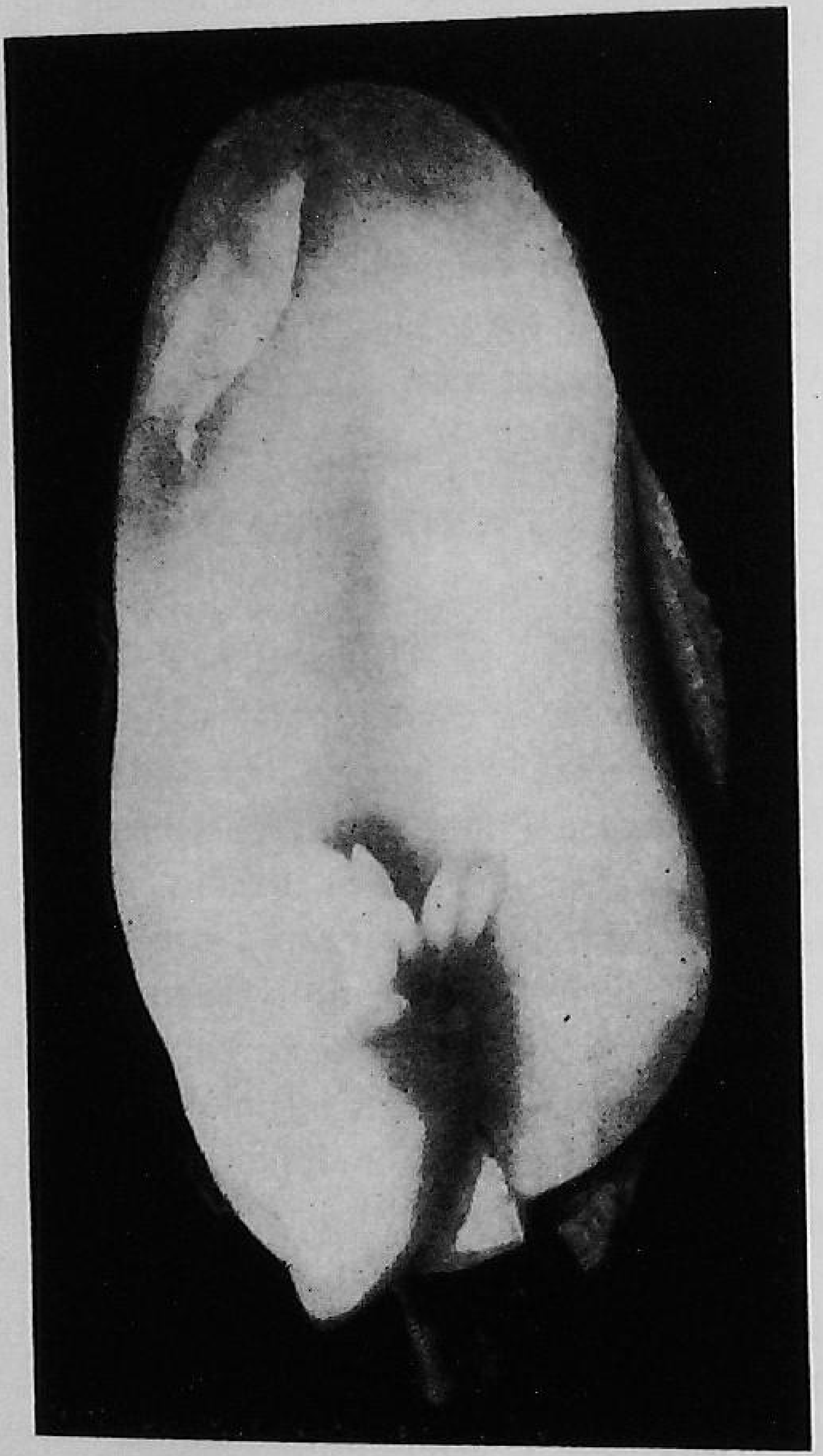

Figure 1.—Mature peanut seed. One cotyledon has been removed to show the straight embryo with its well developed epicotyl and massive radicle. The papery seed coat is visible around the edge of the cotyledon.

seedling is 4 to 5 days old, 25 to 50 lateral roots have appeared (Yarbrough, 77). Figure 3 shows the hypocotyledonary axis grown to a length of 164 mm. while the entire epicotyl has not exceeded the length of the cotyledons, about 20 mm.; in other words, an epicotyl-hypocotyl ratio of ⅛. In 11½ days this root system reaches a length of 30 cm. and produces 100 to 116 laterals (figure 10). Meanwhile the shoot expands

Figure 2.—Peanut seedling, 2 days old. The well defined collar below the smooth hypocotyl marks the region of transition from root to stem. Lateral roots are absent and soil particles cling to the roughened surface of the primary root. *(after Yarbrough, 76.)*

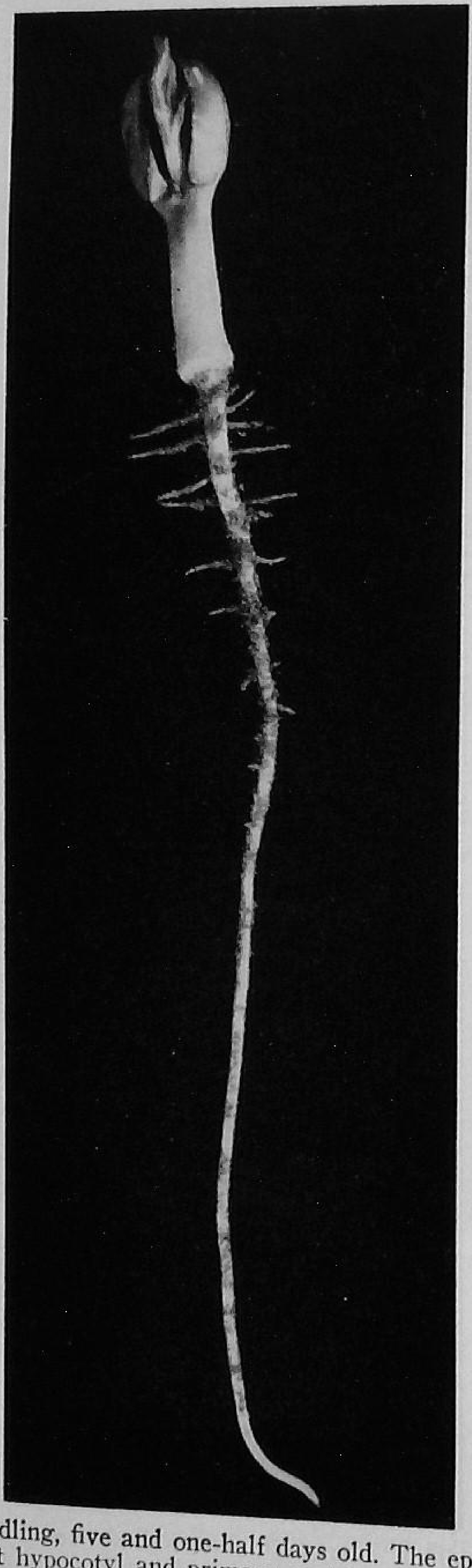

Figure 3.—Peanut seedling, five and one-half days old. The epicotyl barely exceeds the cotyledons but hypocotyl and primary root have a total length of 164 mm. Note the distinct collar at the transition region and the belated appearance of lateral roots. *(after Yarbrough, 76.)*

the foliage leaves laid down in the seed, but no new growth is visible until about 21 days after planting.

ROOT

In a young peanut seedling the root is sharply differentiated from the hypocotyl by an abrupt constriction (figures 2 and 3). This constriction or collar marks precisely the transition zone (59, 76). Just at this collar the intact epidermis of the hypocotyl gives way to the non-epidermal outer layers of the primary root. Even superficial examination reveals the fact that no true epidermis exists on the peanut root. Figure 2 shows the soil clinging to the broken, sloughing surface. This condition in peanut roots, and its expected morphological corollary, the absence of root hairs, have been observed by Pettit (50) and Richter (59). Richter suggested that the ragged, uneven surface of peanut roots, where the root hairs would normally be expected to occur, served as an active absorptive surface. Waldron (75) reported root hairs on peanuts and showed that under ordinary conditions they usually appeared as rosettes of hairs at the junctions of the lateral and main roots, but Reed (55) reported that few hairs occurred under field conditions. The internal development and differentiation of tissues in the peanut root were first touched upon by Richter in 1899. Yarbrough (76) has recently published a description of their internal development.

A longitudinal section through the growing tip of a young root shows the root cap, root initials, stele, and cortex. Among the root initials there is no specific differentiation into initiating layers. The root cap, cortex, and stele are laid down by the initials most proximal to these areas by appropriate longitudinal, tangential, or radial divisions.

The absence of epidermal initials ultimately results in the absence of an intact epidermis and, consequently, the almost complete lack of root hairs. The cross section in figure 4 shows that outside the cortex there is a cork cambium-like region which by both radial and tangential cell divisions lays down the closely packed absorbing cells which Richter believed substituted for root hairs as absorbing surfaces. The sloughing external cells are thus continually supplied from within. This region of the root extends only 8 to 10 mm. back from the root cap and has been shown to be an actively absorbing region in dye absorption studies by both Richter and Yarbrough. Yarbrough emphasizes the probability that the importance of this region in absorption is confined to mineral ions, a fact of considerable significance when one considers the ultimate position of such maristems in the mature root system. With respect to the limited

occurrence of root hairs, Yarbrough's results confirm those of Badami (3) and Waldron (75) that both high temperature and high humidity favor their production.

If one examines a cross section of the root (figure 4), it can be seen that the innermost row of cortex cells constitutes a typical endodermis.

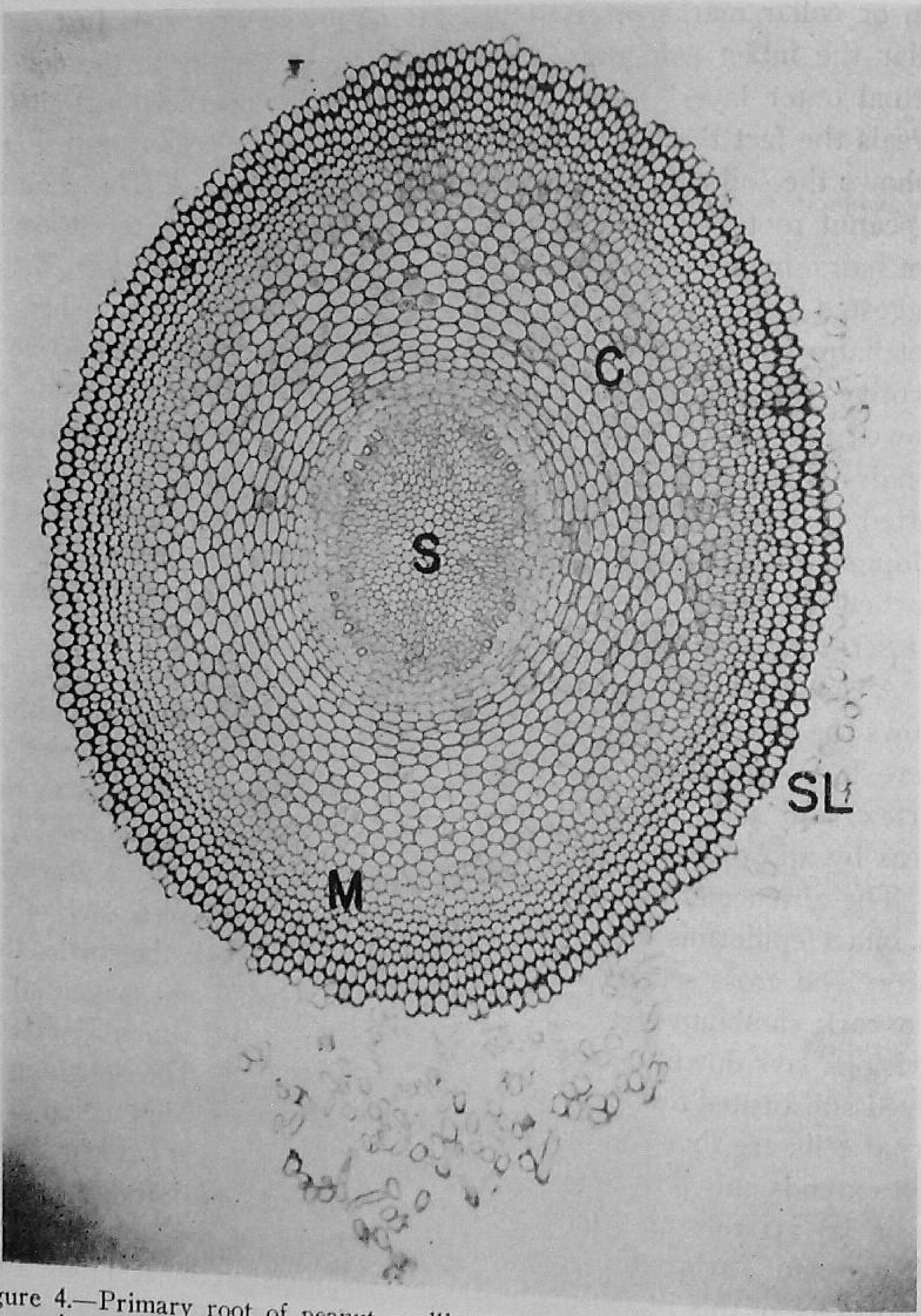

Figure 4.—Primary root of peanut seedling, cross section; s, stele; c, cortex; m, meristematic zone; sl, sloughing outer cells. No epidermis is present on the root. *(after Yarbrough, 76.)*

The central cylinder of the primary root differentiates pericycle, phloem, xylem, and pith in normal fashion. The phloem fibers occur in four homogeneous bands. These mature about the same time or a little later than the last primary xylem. Thus the primary vascular structure of the root is tetrarch, external evidence of which can be seen in the 4-ranked arrangement of the first lateral roots.

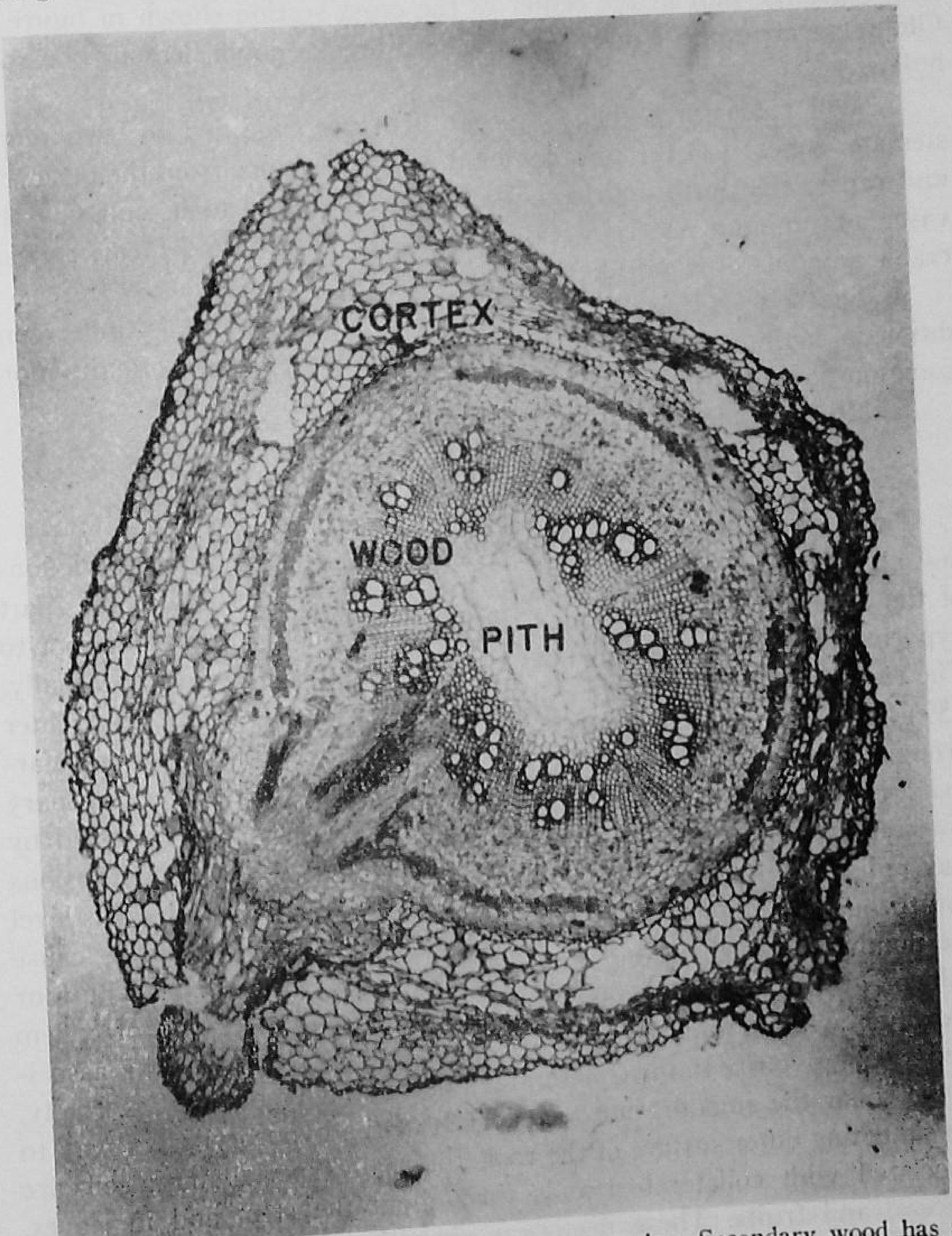

Figure 5.—Older primary root of peanut, cross section. Secondary wood has appeared; cortex and pith have begun to disintegrate. *(after Yarbrough, 76.)*

Yarbrough (76) emphasizes the following characteristic features of the root system in the young peanut seedling:

1. The central stele shows a tetrarch or four-pointed pattern of four xylem groups with alternating phloem groups. This is the usual radial arrangement of conducting tissue found in roots of all higher plants.

2. Although Compton (19) stated that the peanut root has no pith, note the large pith in the center of the cross section shown in figure 4. Old roots are quite woody and the pith breaks down, leaving the root hollow.

3. Old roots have their internal structure modified by two meristematic zones: (a) the cork cambium which develops from the pericycle and causes the death and loss of all tissues external to it, and (b) the vascular cambium which develops within the phloem and forms considerable amounts of wood (figure 5).

4. Sparsely scattered hairs may be seen on peanut roots under conditions of high temperature and high humidity with rosettes of hairs more common at the bases of some lateral roots.

5. No true epidermis exists on peanut roots.

TRANSITION FROM ROOT TO STEM

The hypocotyl, that portion of the peanut stem below the cotyledons and above the root, never emerges from the soil and thus becomes part of the anchoring root system of the plant. The transition from root to hypocotyl, however, is marked and abrupt, both internally and externally. The transition from radial to collateral bundles was described by Richter (59), by Compton (19) and by Yarbrough (76). According to Yarbrough, ". . . there are four exarch xylem groups in the upper primary root; just below the collar there are eight endarch groups formed by division of each original one; in the collar or slightly above some fusions may reduce the xylem groups to seven, six, or even four; above this level and throughout the hypocotyl further branching and anastomosing cause the number of xylem groups to vary from nine to eighteen." The four phloem groups of the primary root pass through the zone of xylem transition without modification but finally divide and with the associated xylem give rise to the collateral bundles of the hypocotyl. Externally, at the collar the smooth, intact epidermis of the hypocotyl gives way to the sloughing outer surface of the root. Internally, special tannin cells are associated with collateral strands throughout the stem and in leaves, flowers, and fruits. These disappear abruptly at the collar. Thus the transition zone from root to stem is defined by:

1. The abrupt out-swelling of the collar.
2. The sudden appearance of the intact epidermis of the hypocotyl at the collar.
3. The transition from radial to collateral arrangement of the vascular strands.
4. The immediate appearance of tannin cells associated with the collateral bundles.

HYPOCOTYL

The hypocotyl in the seedling stage is very succulent, white, and smooth. The central stele may be quite green even though the hypocotyl is

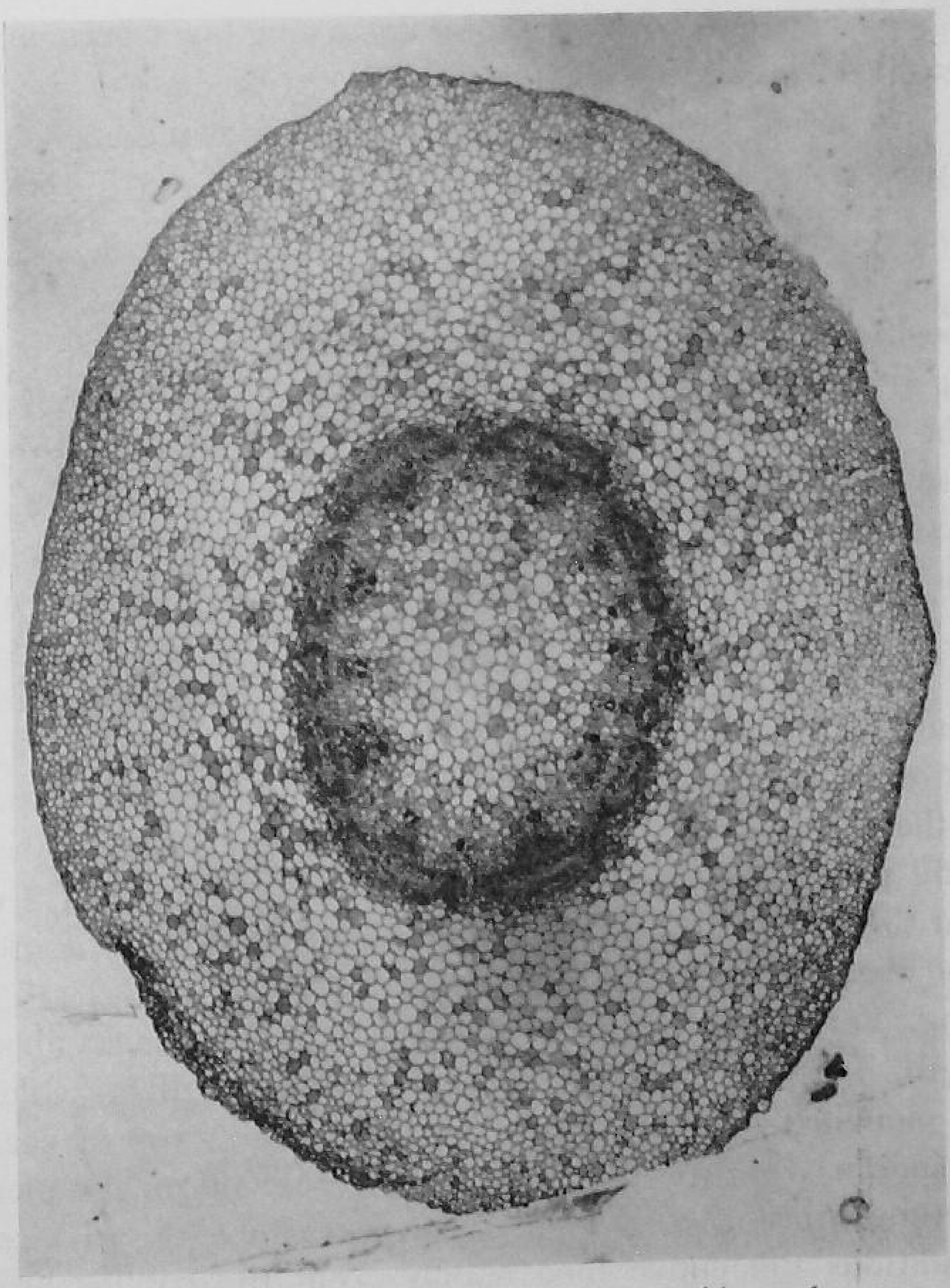

Figure 6.—Young peanut hypocotyl, cross section midway between collar and cotyledons. Note the intact epidermis, wide cortex, stele with collateral vascular traces, and central pith. *(after Yarbrough, 76.)*

always underground and the stele is surrounded by a fleshy cortex. In the dormant seed most of the radicle is actually hypocotyl tissue and is filled with stored food. During germination the hypocotyl, cortex, and pith may serve as way-station, storage tissues for food moving out of the cotyledons to the roots.

The hypocotyl, when cut transversely (figure 6), shows an intact epidermis covered by a thin cuticle, a wide cortex where much stored food may be found, and a central stele in which the conducting tissues, xylem and phloem, are arranged on the collateral plan. The vascular bundles of the hypocotyl increase to nine or more as compared to four in the root and surround a large pith. As the hypocotyl becomes older (10 to 30 days) it undergoes two significant changes, the first of which is a collapse of epidermis and much of the cortex. The collapsing layer becomes soft and may be easily rubbed off. Secondly, the collar at the base of the hypocotyl becomes very woody and hard. The pith breaks down and the hypocotyl ultimately becomes a hollow woody axis (76).

COTYLEDONS

The position of the cotyledons during germination determines whether a seedling is classified as epigeal, i.e., with its cotyledons above the surface of the ground as in the green bean or the soybean, or hypogeal as in the case of the garden or English pea. In the first case the growth of the hypocotyl pushes the cotyledons upward until they appear above the surface of the soil. In the latter case the cotyledons remain just where the seed was placed when planted. Peanuts do neither. The cotyledons rise with the hypocotyl until the soil surface is reached and there they stop. Bouffil (13) said that they were hypogeal; Yarbrough (76) said that they were not epigeal. This growth of the hypocotyl which determines the position of the cotyledons is a function of the depth of planting. Bouffil planted seeds of peanuts at depths of 3, 6, and 9 cm., and found that the position of the planted seed determined the position of the collar, and that the length of the hypocotyl was clearly related to depth of planting. Yarbrough (76) has made a similar statement about hypocotyl length. This fact is strikingly borne out in seedlings volunteering in newly ploughed fields in the spring following a crop of peanuts the previous summer. Many of these peanuts germinate on the plough sole and sometimes must rise 12-14 cm. before reaching the surface. Under these conditions the entire food supply from the cotyledons may be exhausted and the young epicotyls emerge pale and yellow. When this happens it has been consistently noted that with increasing depth of

planting the hypocotyl length approaches a maximum of 10 to 12 cm. and any further elongation necessary for emergence is made by the epicotyl. This elongation of the epicotyl does not await attainment of maximum hypocotyl length but appears to develop continuously in direct proportion to depth of planting. It has likewise been observed that the length of primary root varies inversely with planting depth to such an extent that peanuts germinating at their maximum depth for emergence are almost devoid of roots. Bouffil illustrates this clearly in his photograph, figure 1, page 10. At ordinary planting depths the cotyledons (figure 7) begin to shrivel (figure 8) as the foods leave them and go into the expanding root and shoot systems. Twenty days after germination extreme shrinkage (figure 9) is apparent.

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Figure 7.—Cotyledon from 5-day old peanut seedling, cross section. The abundance of stored food at this stage is revealed by the deeply stained cell contents. *(after Yarbrough, 76.)*

EPICOTYL

Bouffil (13) divided the life span of the peanut into three stages: 1. germination, 2. preflowering, 3. flowering, fruiting, and maturation. The first of these covered the period of time necessary for emergence, i.e., in Senegal, about 4 days. The period of preflowering extended from the end of the first period to the appearance of the first flower, or about 26 days. The third stage, flowering, fruiting, and maturation, began with the first flower and lasted to maturity or about 80 to 90 days. This life span corresponds to the earliest peanuts known to growers in the United States. Comparable periods in some of the types grown in America would be 7 to 10 days, 30 days, and 120 days.

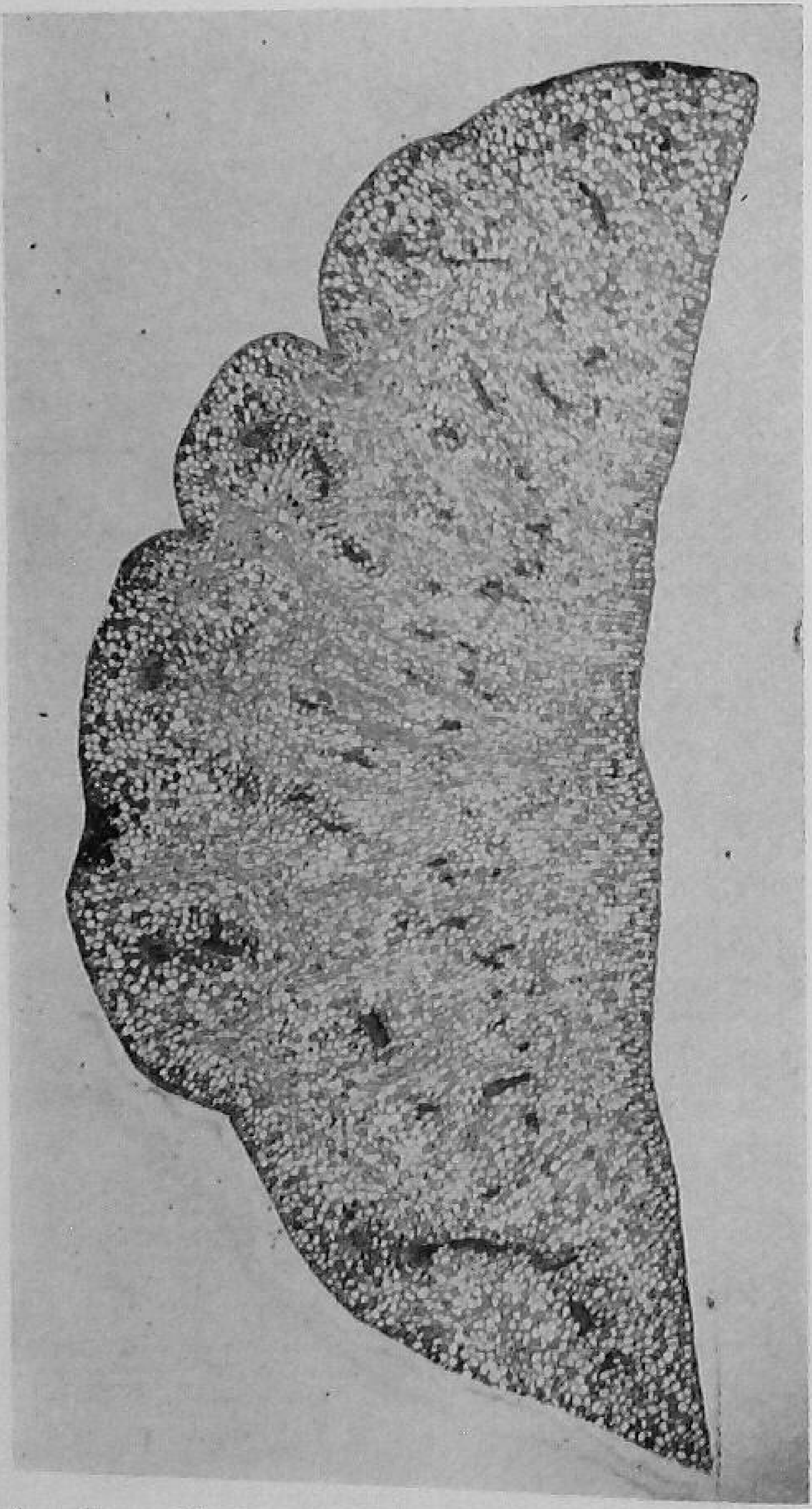


Figure 8.—Cotyledon from 11-day old peanut seedling, cross section. In contrast to the condition at five days, much of the stored food has disappeared and the cell contents are lightly stained. Irregular dark patches result from the collapse of the tissues in these areas. *(after Yarbrough, 76.)*

The basic morphological pattern of the epicotyl is laid down in the seed. Its main axes consists of a central stem and two cotyledonary laterals (figure 10). Contrary to the situation in many plants, at least after the first 3 weeks, the main axis of the shoot exerts little inhibitory effect on lateral axes. The main axis develops first but is soon equalled in length by each of the two cotyledonary laterals, and eventually may be much exceeded by them. From the beginning the plant is provided with three active shoot apices. The third and fourth lateral axes arise from the central stem subtended by its first two foliage leaves. These no doubt are the four branches described by Bouffil (13) but two of them appear much later than he indicates. In Virginia type peanuts additional vegetative branch axes commonly arise from the first two nodes of each

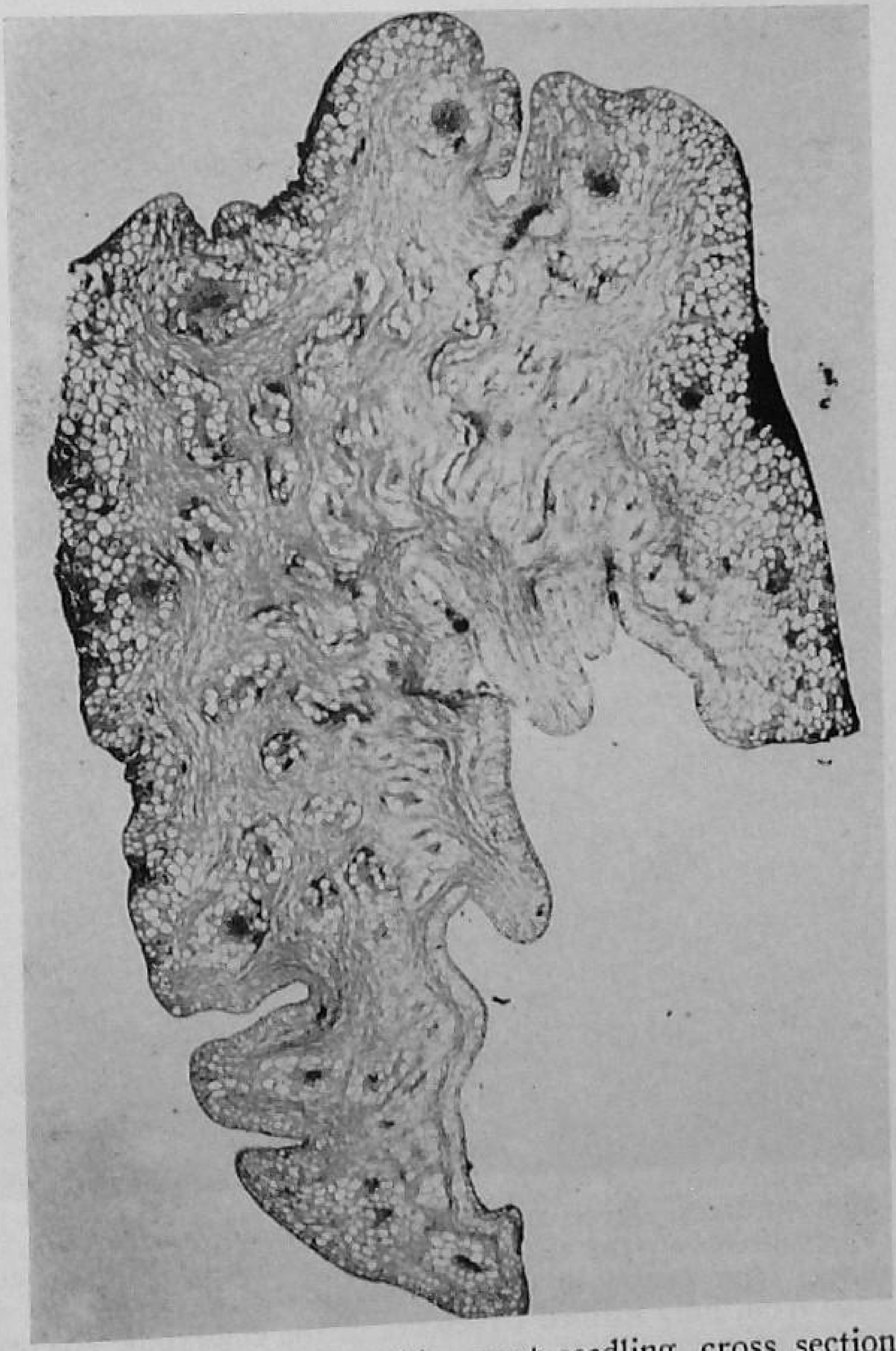


Figure 9.—Cotyledon from 24-day old peanut seedling, cross section. Stored food material absent, tissues collapsed and beginning to disintegrate. *(after Yarbrough, 76.)*

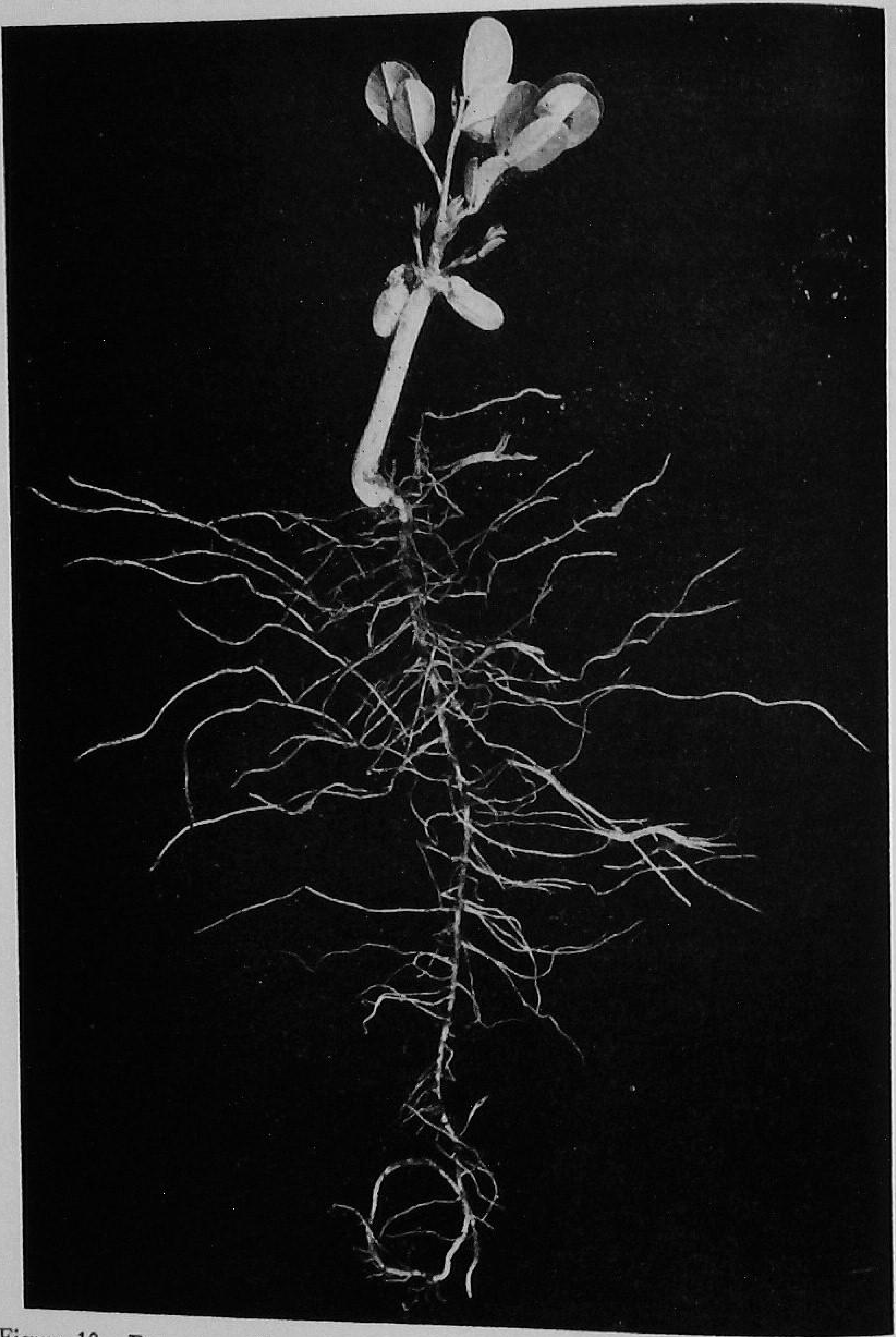


Figure 10.—Peanut seedling, eleven and one-half days old. The root system is well developed. Four leaves of the main axis are visible and the two cotyledonary lateral branches have begun to expand. All of the shoot organs visible here have expanded from fully formed structures of the embryonic epicotyl shown in figure 1. *(after Yarbrough, 76.)*

cotyledonary lateral, subtended by reduced foliar scales known as cataphylls. These are found as the first two foliar organs of all lateral axes. The cataphyllar internodes are usually short and on the lower branches are frequently covered with soil during cultivation.

In Virginia type peanuts the first reproductive branch generally appears in the axil of the first foliage leaf on one of the cotyledonary laterals. No reproductive branches occur directly on the main stem in Virginia. A reproductive branch may occur in the axil of the second cataphyll but none has been reported or observed in the axil of the first cataphyll. The first reproductive branches in Spanish and Valencia types occur at the first cataphyllar nodes on the cotyledonary laterals. Later reproductive branches also occur on the main stem.

VEGETATIVE STRUCTURE OF THE MATURE PLANT

A detailed anatomy of the mature peanut plant has not been written. The general morphology, habit of growth, branching habit, and general appearance of the plant have been described with varying degrees of thoroughness. Much of this description is to be found in the taxonomic treatments of the genus and its relatives. Although we are not primarily concerned here with the systematics of peanuts, we find the published descriptive accounts of the species one of our best sources of general morphological information.

Root

Hoehne (34) has described the genus as perennial. The root systems of all the wild species develop much-branched, woody structures and all, including our cultivated form, last more than one year. In *A. hypogaea* the root system may penetrate to a depth of 3 to 4 feet in cultivated fields (Yarbrough 76). In some wild species the root systems become tuberous and fleshy (figure 11). This characteristic is not confined to *A. tuberosa* but is also found in *A. marginata* (34). When grown in the United States, wild species received from South America show variable development of the tuberous habit, but even in forms generally not thought to possess tubers this character is somewhat apparent. Of the species seen by the authors, only in *A. hypogaea* do the roots appear to be entirely non-tuberous. At present we do not know whether or not this character would develop in specimens of *A. hypogaea* grown for several years. Hoehne (34) considered the tubers to be food storage organs which assist in carrying the plants over unfavorable periods of the year,

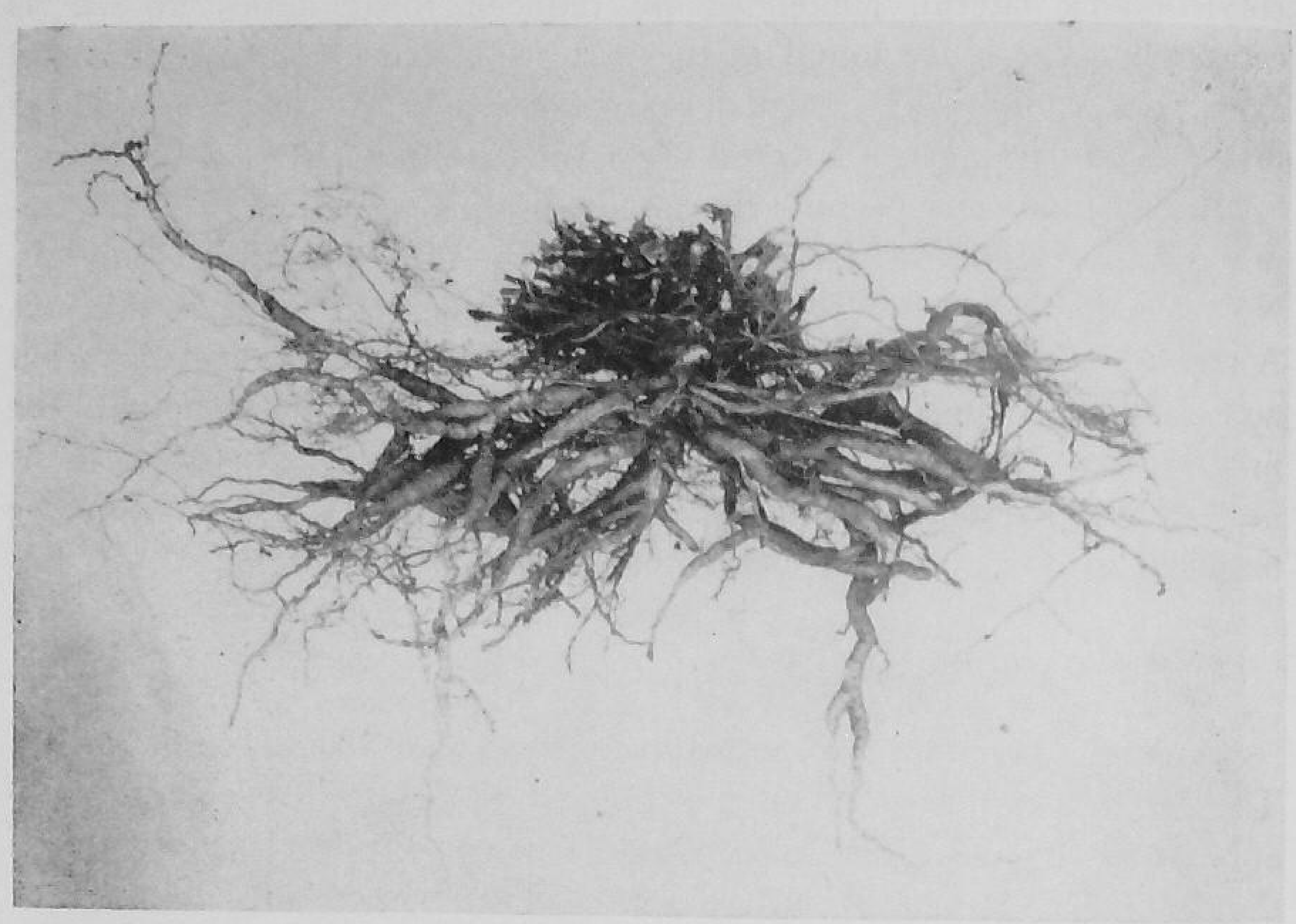


Figure 11.—Tuberous root system of *Arachis marginata*. Tap-rooted as in *A. hypogaea*, this root system differs from the cultivated species in the development of fleshy thickening.

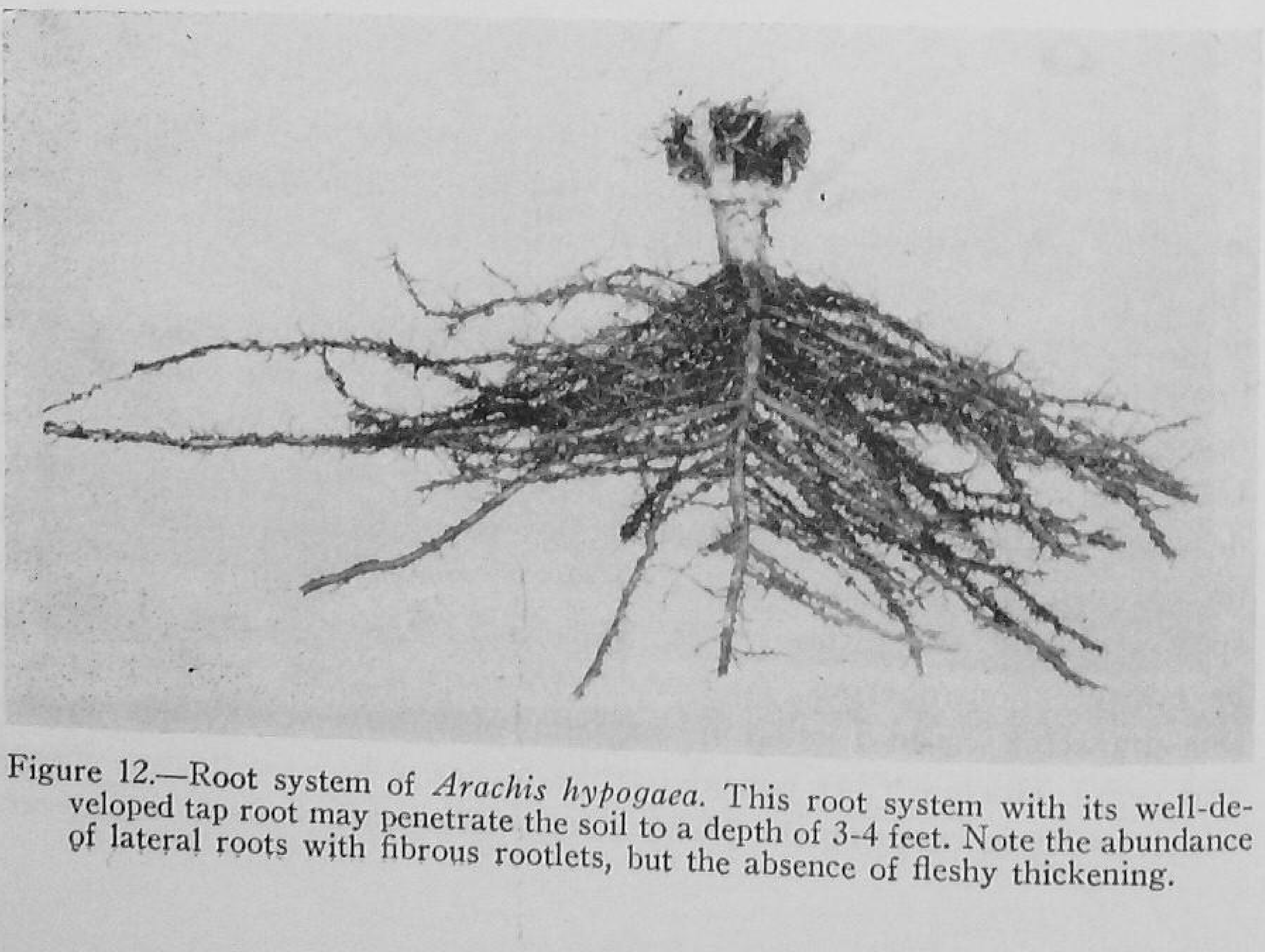


Figure 12.—Root system of *Arachis hypogaea*. This root system with its well-developed tap root may penetrate the soil to a depth of 3-4 feet. Note the abundance of lateral roots with fibrous rootlets, but the absence of fleshy thickening.

So far as is known these structures have not been put to practical use by man.

The root system in *A. hypogaea* consists of a tap root with many laterals (figures 10 and 12) and adventitious roots from the hypocotyl and aerial branches. The nature of the much-branched and vari-formed adventitious roots developing from the bacterial nodules (Prevot, 54) has not been clarified.* Prevot suggested certain possible functions for such roots but these have not been experimentally verified. Some of the wild species frequently develop extensive branching roots from the pegs (Gregory, 27). *A. hypogaea* has been observed to do this occasionally but in such cases the roots can usually be seen to develop from callus tissue following wounding of the peg or pod. The development of root hairs has not been studied sufficiently in *A. hypogaea* or at all in the wild species.

Stems

The cultivated peanut is ordinarily (1) erect (bunch) or (2) prostrate (running) although intermediate growth forms occur. In both cases there is an erect primary branch which serves as the axis of the plant and gives rise to various lateral branches. The central axis (main stem) develops from the terminal bud of the epicotyl and is flanked by two opposite, lateral branches which arise from the respective cotyledonary axils. The central axis is always erect but may be relatively short in the prostrate varieties. In the erect varieties the lateral branches are also erect or ascending, but even in these types the plants may become semidecumbent as growth proceeds. In contrast, the main lateral branches of the truly prostrate varieties always grow peripherally from the main axis and usually lie within an inch of the ground except at their tips, which may be somewhat ascending.

Working with cuttings, Harvey and Schultz (29) observed in an erect type that main stem and lateral cuttings produced plants which were essentially similar in flowering habit to the control plants grown from seed. In two other varieties, characterized by non-flowering main stems, the main stem cuttings produced no flowers on the original axis but produced laterals in a manner comparable to the seedlings. The cuttings of the laterals continued to behave as laterals, however, and produced inflorescences on all branches including the initial axis which had been cut from the parent lateral. One of these varieties was distinctly

* In his figure 13, Prevot (54) illustrated a cluster of these roots on which the nodules produced a number of white rootlets, having the appearance of roots grown under the influence of heteroauxin. These rootlets were thickened, short, and often had claviform ends. It may be noted that these roots appear very similar to those infested with nematodes.

prostrate and the cuttings of its laterals not only flowered, but also continued to be prostrate, growing entirely in one direction from the original point of root attachment. Clearly in this case, the polarity in development which controlled the original lateral branch was maintained independently in the excised portions.

The stems of *A. hypogaea* are angular at first, containing a solid pith which breaks down eventually so that old stems are hollow. The angularity is also lost with age, the older branches becoming cylindrical. There is no indication of woody development in the aerial portions of *Arachis*. The genus consists exclusively of herbaceous perennials; possibly some forms of *A. hypogaea* should be considered annual.

A variety of other growth forms are found among the wild species of *Arachis*. Hoehne (34) described these briefly in his monograph but attached little systematic importance to the variation present. The rhizomatous habit is clearly present in *A. glabrata*, for example, while several of the species are stoloniferous, the stolons being partially buried at times.

The pattern, order, and kinds of branching in the peanut are one of the most interesting botanical features of the plant. Richter (59) gave a brief description of branching orders wherein he let the central stem axis of the plant be an axis of the n order. Branches arising from the n order axis were of $n + 1$ order and branches arising from $\text{n} + 1$ order axes were $n + 2$ order, etc. Branches arising in the axils of the foliage leaves were of two kinds, (1) vegetative and (2) reproductive. Since reproductive branches normally do not give rise to further branching, their production terminated all further orders of branching. For example, in Richter's material, $n + 3$ order reproductive branches, by their specific morphology, terminated the branching system. Prevot's (54) diagram in his figure 10 shows a branching pattern similar to the type described by Richter (59). We have observed branching systems of several varieties of *A. hypogaea* and found that these differed widely not only in the numbers of branching orders produced but also because they fell into certain well defined patterns.

Leaves

Leaves of peanuts are usually pinnate with two pairs of leaflets. Hoehne (34) reports that at least one species, and perhaps two are normally trifoliate. The leaflets may be elliptic-obovate, (*A. hypogaea*), elliptic-lanceolate, (*A. glabrata*) or almost linear (*A. angustifolia*). The leaflets may have inrolled margins or varying development of marginal hairs. Hoehne (34) makes extensive use of these characters in his description of species. The leaves of the several species may be dark dull

green, dark blue green, pea green or yellow green. In *A. hypogaea* this variation is pronounced and has been shown to be genetic in origin. The dark dull green of one tuberous-rooted wild species (*A. marginata*) has not been seen in *A. hypogaea* but is approached in certain Chinese forms. The genetic segregation for depth of chlorophyll green in *A. hypogaea* leads to the general supposition that the variations in leaf color between wild species are also genetic in nature and are not primarily a matter of mineral nutrition as might be suggested by cultivated fields of *A. hypogaea* differing in available nitrogen, calcium, and other mineral elements.

The arrangement of the leaves on *A. hypogaea* is intimately associated with the branching habit of the plant. The leaves occur alternately, one at each node, and describe a 2/5 phyllotaxy (Richter, 59). Embryonic leaves on the main stem axis are well formed and ordinarily show little or no reduction in size. This is far from the case on all primary and secondary laterals. As one proceeds towards the base from the tips of such branches, the leaves usually show reduction in size and at the lowermost nodes also show a reduction in number of parts and completeness of form until at the first and usually the second node, the leaves are represented by mere scales known as cataphylls. Branches arising in the axils of the foliage leaves may be either vegetative or reproductive. In either case the first two nodes are cataphyllar.

The morphology of the mature foliage leaf of cultivated peanuts has been described rather completely. The leaf is even-pinnate with four obovate to elliptical leaflets. Two large, long-lanceolate stipules enclose the leaf in the bud. Stomata occur on both surfaces of the leaves. Variations in organization of leaves of seedlings and older plants include occasional quinque-foliate, trifoliolate, bifoliolate, and even unifoliolate types.

Reed (55) illustrated sections of the leaflets and emphasized the presence of water storage cells in the spongy mesophyll. This water storage tissue, associated with typical mesophytic leaf structure, led him to speculate concerning the intermediate ecological position of the peanut between xerophyte and mesophyte. These speculations may prove to be well founded, for peanuts are capable of withstanding long periods of dry weather but give a typical mesophytic response to relief by rains. The peanut's ability to withstand adverse water conditions, its adaptation to soils of deep sand, and its geocarpic habit conform to what we know of the habits, geographic distribution, and ecology of other geocarpic and amphicarpic species. Whether the water storage cells of the leaflets play a functional role in this complex of factors is unknown.

REPRODUCTIVE MORPHOLOGY

Inflorescence

Kurtz (41) described the inflorescences of the peanut as two to three-flowered, occurring in the leaf axils, but Pettit (50) merely stated

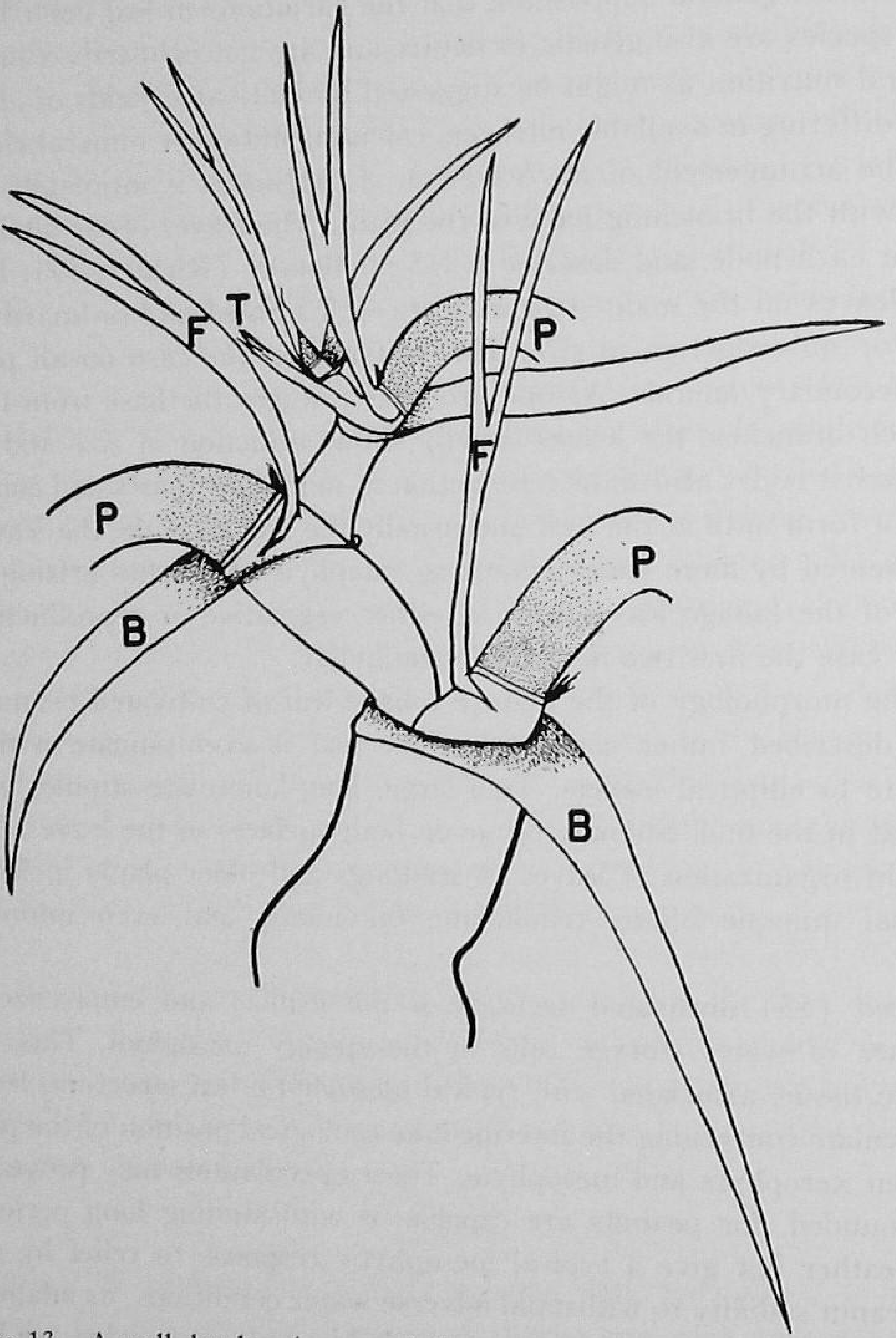


Figure 13.—A well-developed peanut inflorescence; b, bract (cataphyll) subtending a floral branch; f, bract (cataphyll) subtending a flower; p. peg; t, terminal bud of the inflorescence. An axillary floral branch arises at each node of the zig-zag inflorescence axis. The cataphylls have the same relation to the axillary branches of this subpaniculate inflorescence as leaves have to the lateral branches of a vegetative shoot.

that the flowers develop in the axils of the leaves. Richter (59) described the inflorescence with its bracts as an axillary head or compressed spike with a 2/5 phyllotaxy in the arrangement of its flowers.

In systematic treatments of *Arachis*, the inflorescence is described as spicate or subpaniculate. The inflorescences are not terminal but always occur in the axils of foliage leaves or cataphylls. They never occur at the same nodes with vegetative branches and form with the latter a definite branching pattern. Each inflorescence bears three to several flowers. The flowers usually appear one at a time but two may open simultaneously in the Spanish type. Flowers on the same inflorescence may appear daily or at intervals of several days.

An inflorescence (figure 13) irrespective of whether it arises in the axil of a foliage leaf or in the axil of a cataphyll, produces a cataphyll at its first node. Each successive node of the inflorescence also has its cataphyll in the axil of which arises the simple flowering branch. The flowering branch is exceedingly short and possesses a single cataphyll, bifid or simple, in the axil of which the flower bud appears to develop. The production of the flower terminates further branching. The inflorescence can be seen then as a reduced and compressed replica of the vegetative shoot reduplicating its phyllotaxy and axillary buds, differing largely from the latter in the reduction of organs and the suppression of further growth through the production of flowers. The internodes of the central axis of the inflorescence may later elongate, producing a much expanded fruiting structure. The growing point of the central axis occasionally becomes vegetative and pursues a limited amount of growth. New inflorescences may then be laid down in the axils of the foliage leaves occurring at the end of the oroginal inflorescence. Thus it can be seen that what is customarily a reduced and simplified branching system sometimes may become so involved that at maturity the untrained observer cannot distinguish vegetative from reproductive branches.

Flower

The flowers (figure 14) of *Arachis* are yellow, papilionate, and sessile. The development of a remarkable perigyny involving an unusually long hypanthium or "calyx tube" has led to the erroneous supposition that the flowers are long pedicellate. The base of the hypanthium is actually inserted practically at the end of the simple flowering branch and is subtended directly by its cataphyllar bract. The hypanthium is pubescent. The external portion of the tube expands above into five calyx teeth, four of which are fused into a superior lip which stands back of the

standard. The fifth tooth is linear and lies under the keel. The petals and staminal column are adnate at their bases and are inserted together at the summit of the tube. The standard is broadly inserted while the wings and keel are attached by means of claws. The staminal column is usually

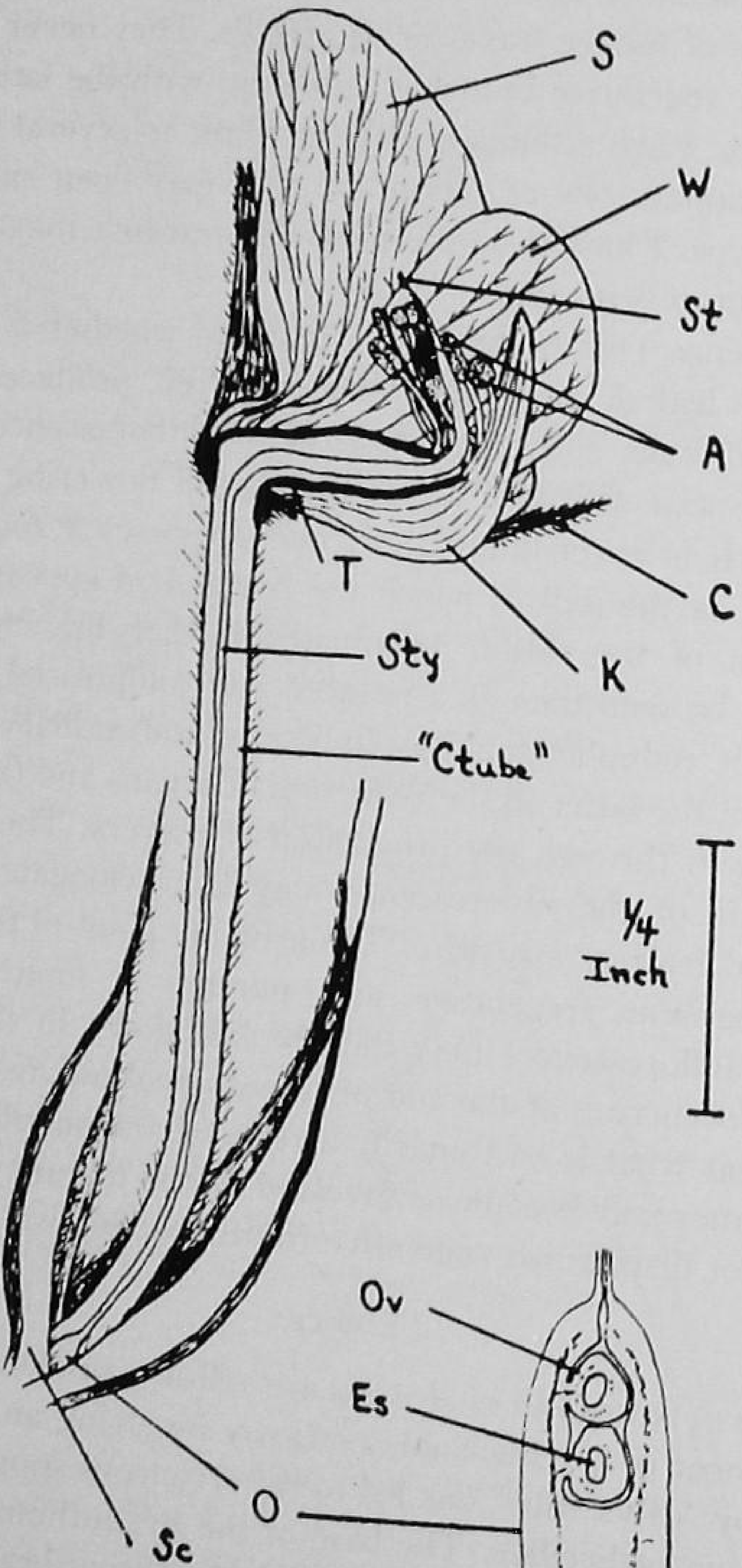


Figure 14.—A peanut flower as seen in longitudinal optical section. S, standard; W, wing; St, stigma; A, anthers; C. calyx lobe; K, keel; T, staminal column; Style; "C tube", hypanthium ("calyx tube"); O, ovary; Sc, bracts (b and f of fig. 13). At lower right the ovary (O) is shown in enlarged section; Ov, ovule; Es. embryo sac. *(after Smith, 66.)*

composed of ten filaments, eight of which are normally anther bearing. The filaments are fused through one-half to two-thirds of their lengths. The stamens occur in two series, four bearing oblong, adnate, introrse anthers which alternate with four filaments bearing globose, dorsifixed anthers. Three of the oblong anthers are biloculate; the fourth, adjacent to the sterile filaments, is usually uniloculate. The four globose anthers are uniloculate. In bud stages the filaments bearing the oblong anthers exceed the others. The staminal column lies horizontally to the hypanthium. At the point of separation the free ends of the filaments are sharply reflexed toward the standard, forming acute angles with their fused bases. The pistil consists of a single, sessile carpel (Smith, 66),1.5 mm. long and 0.5 mm. in basal diameter, surmounted obliquely by the long filiform style which extends through the hypanthium, bends sharply through the staminal column, bends sharply again with the reflexed filaments, and ends in a club-shaped stigma above the anthers. Near its summit on the surface facing the standard, the style is clothed with upward slanting hairs.

Twenty-four hours before anthesis the flower bud is 6 to 10 mm. long (Smith, 66). During the day elongation of the bud proceeds slowly but when night falls elongation accelerates. At the time of anthesis, near sunrise the following day, the flowers may be from 50-70 mm. long. The oblong anthers dehisce just before, sometimes after petal expansion. The globose anthers dehisce subsequent to further elongation of their filaments, which eventually equal or exceed those of the oblong group (Badami, 3; Smith, 66).

Peanut flowers which are fresh and turgid at sunrise are usually wilted by midday, although they last longer in cool weather. On the day after flowering all the flower parts except the small, sessile ovary have withered, as Didrichsen (22) clearly demonstrated in 1866. The hypanthium soon abscisses leaving a circular scar at the base of the ovary. The old flower parts sometimes adhere to the tip of the ovary during early peg growth.

Peg

The peg is the most distinctive feature of the peanut plant, for it is by means of this structure that the aerial flowers come to mature their fruits underground (figure 15). The peg has been variously described as an apetalous flower or more recently as a gynophore, a stalk upon which the ovary rests. The various interpretations and terms applied to this structure have been reviewed by Smith (66). He has defined the peg as

"the young fruit during the stalk-like phases of development which intervene between syngamy and fruit enlargement." Smith has shown that this stalk-like organ is not a gynophore but in reality the ovary, elongated by the growth of an intercalary meristem in its base. Jacobs (39) has described the development of this meristem and the differentiation of the tissues arising from it. He has shown that the vascular strands extend through the meristematic region to the base of the ovarian cavity. The loculus of the ovary, distal to meristem in the tip of the peg, contains the 2 to 6 ovules.

The ovary is enclosed by cataphylls of the inflorescence, which in turn are covered by the stipules of the subtending leaf. Peg growth begins immediately after fertilization and the peg usually appears from within the enclosing bracts and stipules several days after anthesis. Early growth is slow but gradually accelerates until the pegs are elongating very rapidly.

The peg is positively geotropic. Charles Darwin (21) showed in 1880 that the peg was not negatively phototropic but did respond to the force of gravity. The later observations of Badami (3), Jacobs (39), Shibuya (65), Theune (71) and Waldron (75) have supported this view. The ultimate length of a peg and the time required for it to reach the soil is determined by the initial distance from the ground. Pegs inserted more than 15 cm. above the soil surface usually fail to reach the ground. In such circumstances, the peg tips usually fail to reach the ground. In such circumstances, the peg tips usually die and pod and seed development do not occur. Exceptionally, ovule enlargement does occur and viable seed develop in aerial pegs, but normal pods are not formed (Gregory in Smith, 66).

Upon penetrating the soil the peg commonly grows to a depth of 2 to 7 cm. (but may be covered much deeper than this by cultivation). For several centimeters immediately above the soil surface the peg sometimes becomes fleshy and much thickened, and loses its green or purple color. Its lenticels become enlarged and irregular. Many multicellular hairs may be found on the peg surface. Underground the peg may become similarly expanded and have copious hairs. The function of these hairs is problematical. Pettit (50) and Waldron (75) have interpreted the hairs of the peg and pod as "root hairs" in structure and function, but Richter (59) found their cell walls suberized. He suggested that they anchored the peg in the soil. These hairs are not root hairs but are multicellular trichomes characteristic of stems.

Pod

When the peg reaches its maximum penetration of the soil it loses its geotropism and the tip turns to a horizontal position. At the same time the pod begins to enlarge and development rapidly ensues. Enlargement of the pod proceeds from base to apex (figure 15). Early stages resemble

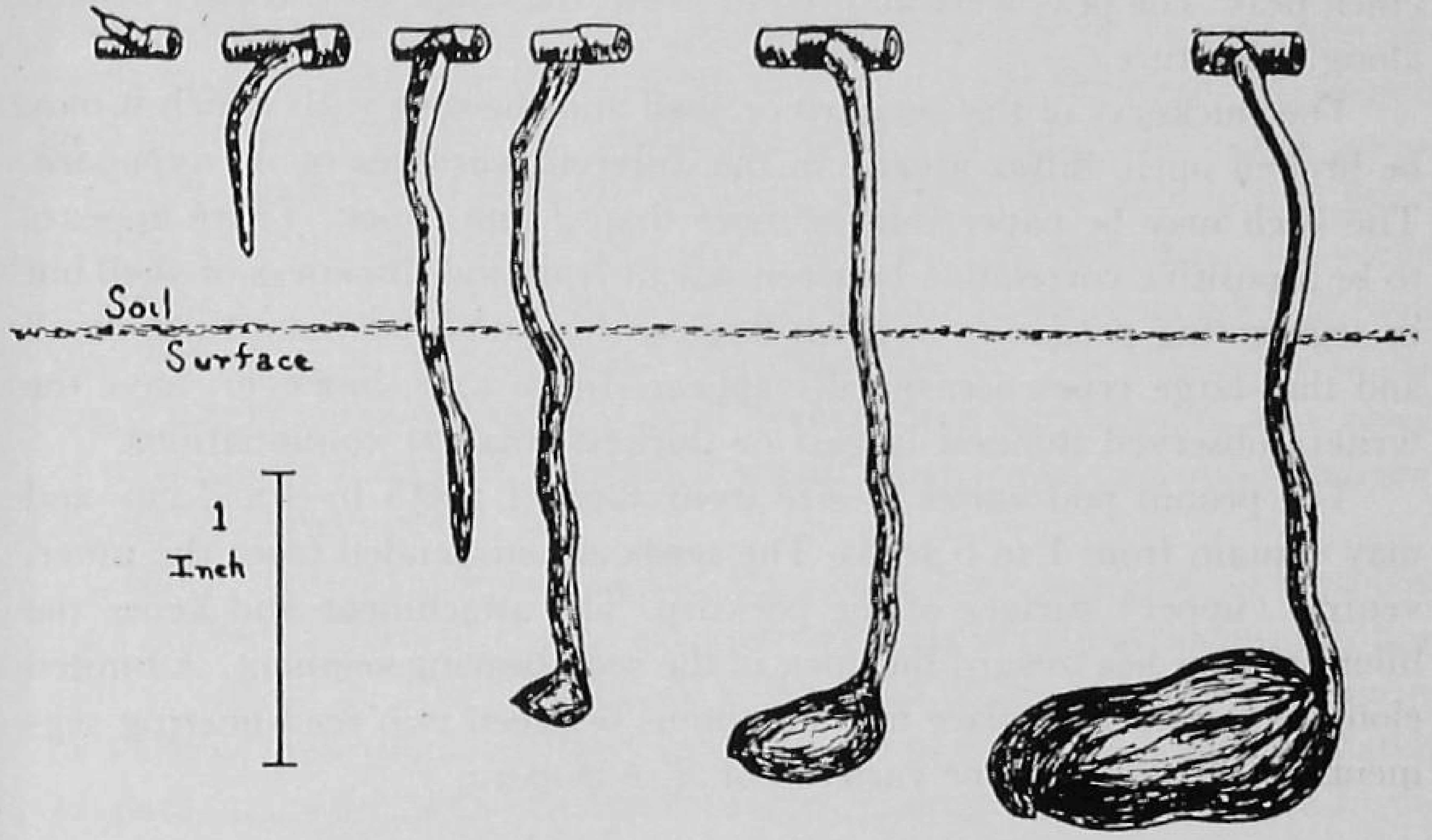


Figure 15.—Successive stages in the development of a peanut fruit. Left to right: an ovary at time of fertilization; young aerial peg; elongated peg after soil penetration; the tip of the peg turned to a horizontal position and the beginning of pod enlargement; early immature stage of pod development; mature fruit. *(after Smith, 66.)*

one-seeded pods in appearance. The more rapid development of the basal segment is associated with the earlier development of the basal seed. When the apical seed aborts, as occurs frequently, enlargement of the apical portion proceeds no further.

At maturity, the shell is usually reticulate and more or less constricted between the seeds. According to Thompson (72) and Russell (63) the superficial exocarp layers flake off during development. The characteristic reticulations underlying the veins are ridges of mechanical tissue arising as outward extensions of the sclerenchymatous mesocarp layer. This layer is continuous except at the sutures. The endocarp consists of a parenchymatous tissue which surrounds the ovules during development. The cells of the endocarp lose their contents and their walls collapse as the pod matures.

The peanut fruit is a one-loculed, structurally dehiscent, but func-

tionally indehiscent legume. Under pressure the pod tends to split along a longitudinal ventral suture. Examining cross sections, Richter (59) observed that the mechanical tissue of the mesocarp was interrupted along this line. He demonstrated that this was the line of normal dehiscence by cutting the pod into rings and then passing the rings over suitably sized chick peas. The peas were allowed to swell; the rings were always broken along the suture.

The thickness of the pericarp or shell and the ease with which it may be broken open, differ greatly in the different varieties of *A. hypogaea.* The shell may be paper thin or more than 2 mm. thick. There appears to be a positive correlation between size of fruit and thickness of shell but in segregating progenies of thick-large x thin-small peanuts, thick-small and thin-large types occasionally appear. In no case, however, have the writers observed thinnest-largest or thickest-smallest combinations.

The peanut pod varies in size from about 1 x 0.5 to 8 x 2 cm. and may contain from 1 to 6 seeds. The seeds are suspended from the inner, ventral (upper) surface of the pericarp. The attachment and hence the hilum always lies toward the apex of the seed-bearing segment. A limited elongation may take place in the isthmus between two seed-bearing segments of the pod in some varieties of *A. hypogaea.*

Embryo and Seed

The internal processes leading to the formation of the embryo sac and the embryo were first treated by Reed (55) and with somewhat greater accuracy by Banerji (4). Embryo sac development and early embryo and endosperm growth have been more recently and fully treated by Smith (68). The frequent occurrence of seed failure, commonly observed as "pops" and one-seeded pods in cultivated peanuts, led Smith to investigate the basic reproductive processes which occur in the ovule just before and after flowering.

In the peanut, a single megaspore mother cell in each ovule undergoes a normal meiosis and produces four megaspores. The lowest (chalazal) spore develops into the 7-celled, 8-nucleate embryo sac, while the other spores degenerate. This embryo sac corresponds to the "normal type" found in other legumes and found in the majority of the investigated cases in flowering plants. By the time of pollination, the synergids and antipodal cells have usually degenerated so that the sac consists of only the egg cell and a large central cell containing the two polar nuclei.

The union of egg and sperm occurs 12 to 16 hours after pollination.

AG30

At the same time, the polar nuclei fuses with the second sperm nucleus. The primary endosperm nucleus resulting from this triple fusion divides first, usually within 8 to 12 hours after fertilization. The zygote has usually divided to form a two-celled embryo within 36 hours.

During the first 10 to 12 days after flowering, growth proceeds slowly in both embryo and endosperm, but in this same period the peg, after a slow start, grows rapidly and usually approaches or reaches the soil surface. From the fifth to the tenth day of fruit development, the growth and elongation of the peg accelerate rapidly. During this same period cell and nuclear divisions are virtually absent in the embryo and endosperm (Smith, 68). After the tenth day, both embryo and endosperm begin to grow rapidly in normally developing seeds, concurrently with the beginning of underground pod enlargement. The durations of the early stages of both peg and seed development vary widely as a result of position on the plant, competition with other fruits, and other environmental circumstances.

More than 93 percent of the eggs have been reported as fertilized and about 12 percent of the early embryos as aborting during the first two weeks of growth (Smith, 67). As most of the fertilization failures or embryo abortions occurred singly in the apical ovules, approximately 14 percent of the pegs studied contained a single developing seed in the basal position. This value is compared with 18 percent one-segmented, one-seeded pods which were harvested in the control sample. Failure of fertilization and early embryo abortion appear to account for the occurrence of most of the one-seeded fruits so frequently seen.

It is equally evident from these results that normal megasporogenesis, embryo sac development, and fertilization provide no basis for predicting the occurrence of the later seed failures which give rise to the shriveled seeds and empty pods characteristic of the pop condition. When a young seed fails during the peg stage, the portion of the ovary containing it also fails to grow. Failures of the seed after underground pod enlargement has begun do not seem to inhibit the completion of pod development. Thus, recent data (68) are in harmony with the conclusions of Burkhart and Collins (15) and of Colwell and Brady (18) that calcium deficiency in the fruiting zone of the soil is a principal cause of the "pop" condition.

Flowering and Fruiting

Peanut flowers begin to appear 4 to 6 weeks after planting. Richter (59) observed that in contrast to flowers of most plants, those of peanuts are most abundant on the lower nodes. He considered this an adaptation

to the geocarpic habit of the plant. He noted that the pegs and mature fruits are also concentrated at the lower nodes. In more suitable climates than that of Breslau where Richter worked, flowering and peg formation occur much farther up the stem than he suspected, flowers appearing even at the last visible node. He was essentially correct, however, in saying that peg production is suppressed at the upper nodes.

The daily production of flowers during the life of the peanut plant has been described by Shibuya (65), Bouffil (13), and Smith (66). Bouffil illustrated frequencies of flower production by days for five consecutive seasons. He compared his frequency distributions with the distribution given by Shibuya for Formosa as well as with a distribution from material grown in the neighborhood of Paris. All of his graphs and those from Shibuya's data are similar. Smith found also that flower-frequency curves obtained during three seasons from North Carolina material closely resembled those of Bouffil. Careful records of hours of sunlight and amounts of rainfall were available to Bouffil, temperature being virtually constant in Senegal, and he stated that the pattern of flowering was not influenced by meteorological conditions. In the data from the Paris area the number of flowers was much reduced but the general pattern was not altered.

Bouffil's analysis of flowering frequency led him to describe four stages in the progression of flowering: (1) slow increase, (2) fast increase, (3) flowering peak, and (4) decline of flowering. Smith described the onset of flowering as gradual with flower production beginning to accelerate after two to three weeks. Peak production was reached four to six weeks after the first flowers appeared, the time depending upon variety; then flowering decreased at approximately the same rates as the increases occurred. In a Spanish strain, two-thirds of the flowers were produced during a one month period beginning six weeks after planting; in a Virginia runner, four-fifths of the flowers were produced during the third month after planting (figure 16).

The following fertility coefficients for Bouffil's line 24-11 are based on means of 90, 89, and 64 plants, respectively, grown at the M'Bambey Station, Senegal.

	Mean flowers per plant	*Mean pods per plant*	*Fertility coefficient, flowers/pod*
1940	599	133	4.5 (flowers)
1941	751.3	161.3	4.65 "
1942	578	68.8	8.4 "

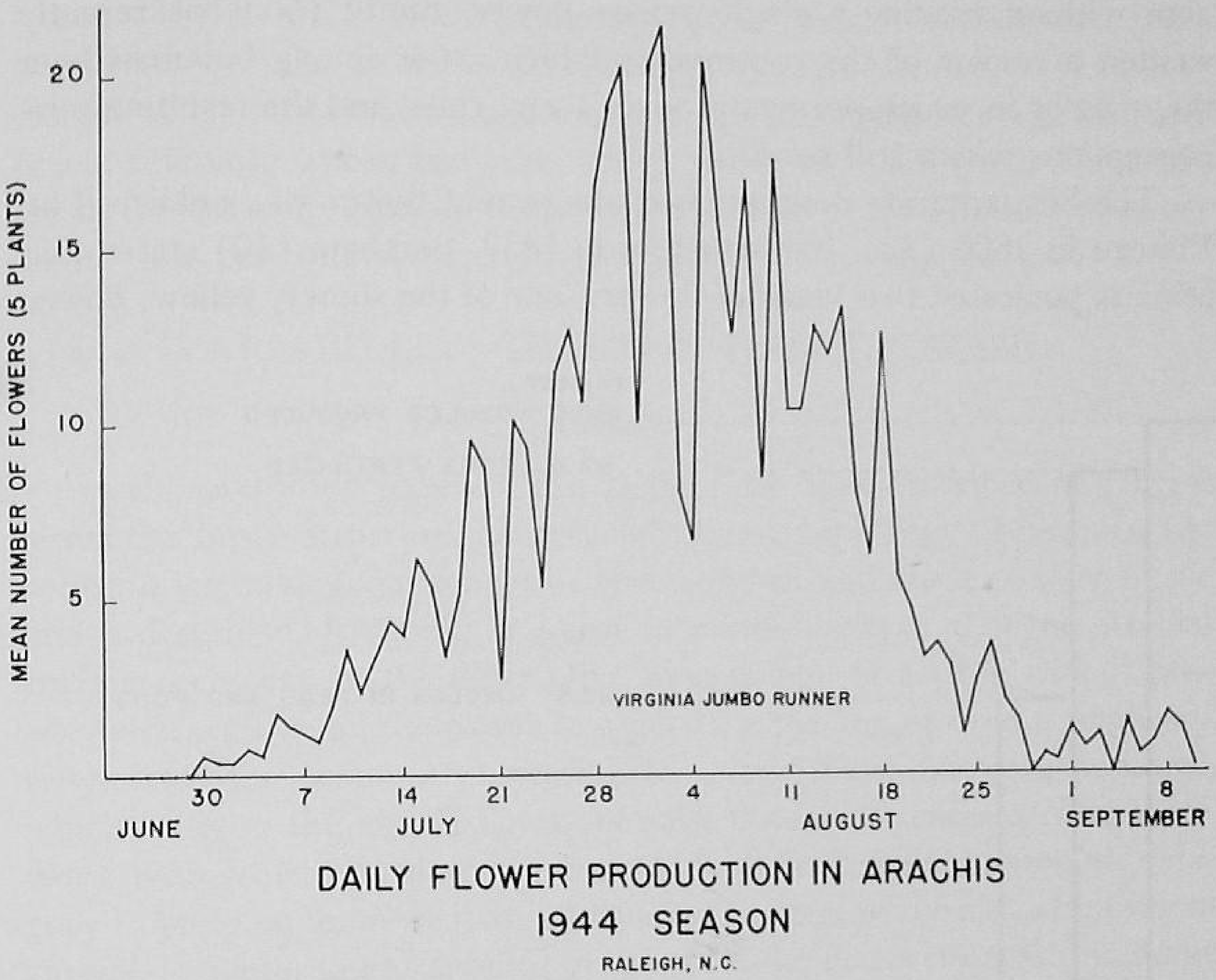


Figure 16.—The seasonal distribution of flower production in a Virginia peanut. *(after Smith, 67.)*

Gregory's data (26) from artificially pollinated flowers, all flowers not used being removed from the plants, showed a fertility coefficient of nearly 2, twice as efficient as Bouffil's 1940 and 1941 values and 4 times as efficient as his 1942 figure. Smith (67) reported that 63 percent of the flowers studied produced pegs and one-third of the pegs developed pods, but only 13.5 percent of the original flowers produced mature fruits (figure 17). Expressed as flowers per fruit the fertility coefficient was 7.5.

Aerial Flower—Subterranean Fruit

From the time that the peanut first became known to Europeans, its flowering and fruiting habits attracted widespread attention. In spite of perennial interest in this botanical curiosity, many misconceptions have arisen concerning the structure of its flowers and their relation to normal fruiting. Even today one can hear the statement that the yellow flowers of peanuts have nothing to do with the production of fruit and that there exist peanuts capable of producing 2000 pounds of nuts per

acre without bearing a single yellow flower. Smith (66) has recently written a review of the controversy which arose among botanists over the manner in which peanuts produce their fruits, and the resulting misconceptions which still persist.

The first accurate description of the peanut flower was published by Poiteau in 1806 (52). Nevertheless, in 1839, Bentham (10) stated that peanuts possessed two kinds of flowers, one of the showy, yellow, flower

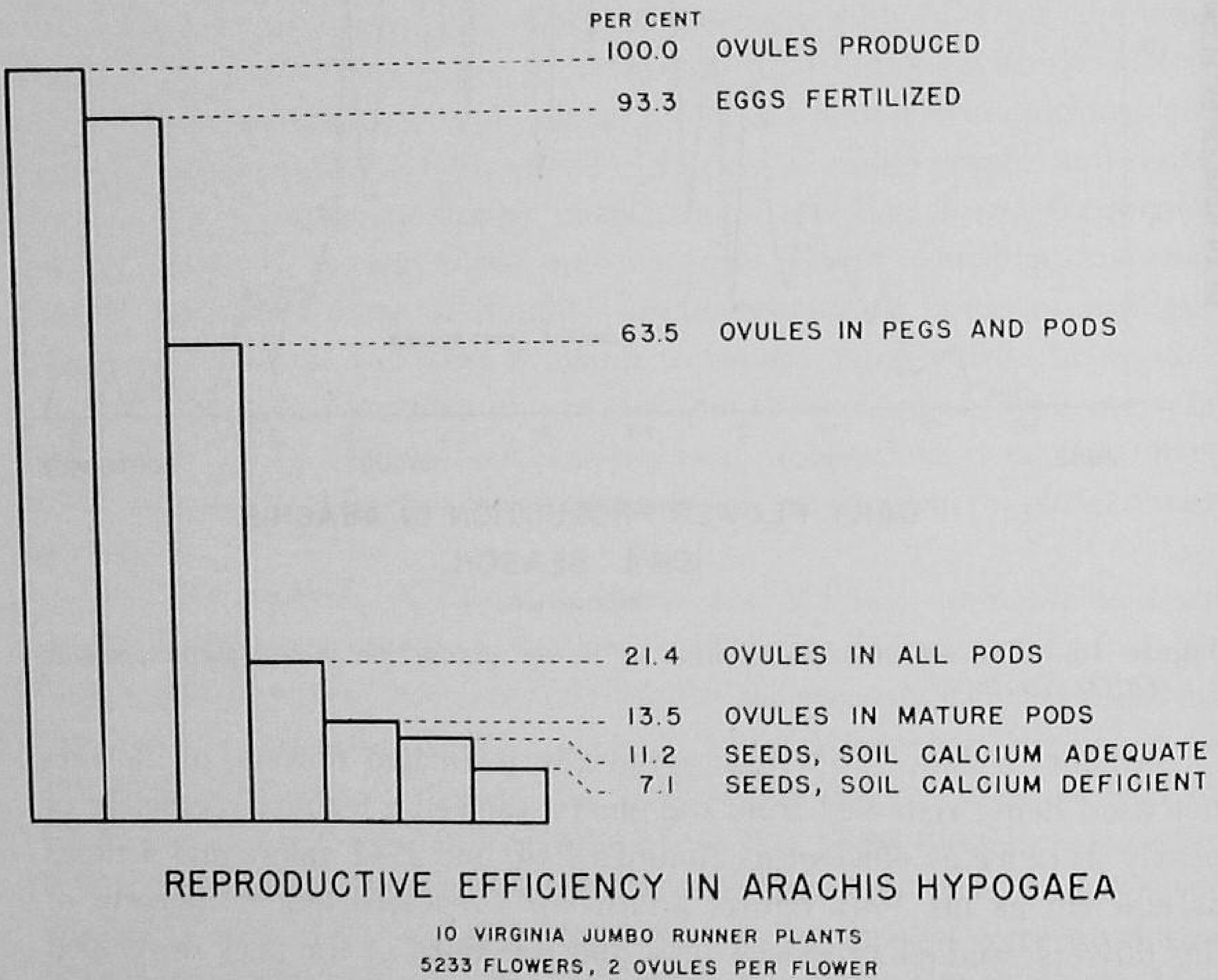


Figure 17. The production of flowers, pegs, pods, and seed in a Virginia peanut. *(after Smith, 67.)*

considered to be sterile; the other, with neither calyx, corolla, nor stamens, which produced the fruit. In other words, he not only did not see the relationship between the flowers and the fruits, but he also thought that the pegs were some kind of peculiar flower. Later Bentham was involved in a controversy with a gentleman from Georgia named Neisler (46) who correctly described the relationship of flowers, pegs, and mature fruits in 1855. Meanwhile, in 1853, Poiteau (53) had restated his position of 1806. Although Bentham recognized his own error in 1856 (see Gray, 25) and corrected it (11), Didrichsen (22) in 1866, and

Kurtz (41) in 1875, failed to discover Bentham's retraction and criticized him severely. Other writers have overlooked Bentham's (11) correction of his mistake, and one may find his erroneous concept in many recent reference works and texts which Smith (66) has cited. The readers of these usually reliable works of the past 40 years will do well to beware while perusing the section dealing with *Arachis hypogaea.*

VARIABILITY, GENETICS AND BREEDING

Variability

In the preceding pages of this chapter we have described in general terms the form, structure, and reproductive morphology of peanuts. On occasion we have given ranges of size, number, and kinds of some of the things described. It should be borne in mind, however, that the detailed studies necessary to the descriptive morphology of a plant cannot possibly characterize all the plants in a genus, a species, or even a single variety. It is the common possession of certain basic features, however, which leads to the establishment of such taxonomic entities. The confidence with which we place a group of plants in a single taxonomic category is based on no more than a conceived average of the almost universal variability found in any natural group. It is the discovery that this range of variation extends beyond the accepted but sometimes ill-defined limits which leads to the creation of new varieties, species, genera, or higher taxonomic categories.

The systematic position of the genus *Arachis* was for a long time a moot question. In 1839 Bentham (10) first properly associated *Arachis* with *Stylosanthes* and *Chapmannia* in the tribe *Hedysareae*. Taubert (70) separated the tribe *Hedysareae* (which includes such plants as beggar's ticks and lespedeza) into six subtribes; the last of these, the *Stylosanthineae,* includes the peanut and its relatives. This subtribe includes only four genera, *Zornia, Chapmannia, Stylosanthes,* and *Arachis*. They possess in common the following features:

"Stamens all united into a closed tube; anthers alternately basally* and dorsally attached; flowers in terminal or axillary spikes or small heads, seldom somewhat raceme-like; leaves pinnate, mostly with few leaflets, without stipels." (Taubert, 70. Translated from the German). *Arachis, Stylosanthes,* and *Chapmannia* form a closely related group, all of them possessing the characteristic tubular hypanthium, pinnate leaves, and straight embryo. *Zornia* differs materially from the rest of the tribe

* Adnate, introrse in *Arachis*—author's note.

in not possessing any of these distinctive features. As described by Burkart (14), Hoehne (34), and Taubert (70) *Arachis* differs chiefly from *Stylosanthes* and *Chapmannia* in producing pegs, being geocarpic, and in producing most of its flowers on the lower nodes of the stem, while *Stylosanthes* and *Chapmannia* have shorter hypanthia, produce no pegs, have aerial fruits, and produce most of their flowers in the upper axils.

The genus *Arachis* itself, before 1839, consisted of only one species, the cultivated peanut, *A. hypogaea*. Bentham, however, described five additional species all collected from the wild in South America. Since that time several additional species have been described.

Hoehne (34,35) recognized twelve species in the genus *Arachis*. These, with their subspecies and forms, are listed below:

A. tuberosa Benth.
A. guaranitica Chod. & Hassl.
A. Diogoi Hoehne
  Form: *typica* Hoehne
  Form: *subglabrata* Hoehne
  Form: *sericeo-villosa* Hoehne
  Form: *submarginata* Hoehne
  Form: *minor* Hoehne
 Subspecies: *major* Hoehne
A. angustifolia (Chod. & Hassl.) Killip
A. helodes Mart.
A. villosa Benth.
A. prostrata Benth.
 Subspecies: Hagenbeckii (Harms) Hoehne
A. marginata Gardn.
  Form: submarginata Hoehne
A. nambyquarae Hoehne
A. hypogaea L.
  Forms: various
A. glabrata Benth.
  Form: *typica* Hoehne
  Form: *major* Hoehne
  Form: *minor* Hoehne
A. villosulicarpa Hoehne

Varieties of Arachis hypogaea L.

The different forms of *A. hypogaea* have stimulated various workers to develop varietal classifications of the cultivated peanut. Taxonomists frequently resort to controversy concerning species delineation because the ultimate nature of organic variation necessarily leads to intergrading forms. If the species problem is difficult, the varietal problem becomes nearly impossible. Yet as certain species grade into one another, varietal clusters tend to assume sufficient distinctness to approximate specific rank. Depending on the chance evolutionary time level at which any observer may happen to approach such clusters, he will find himself confronted with a continuous array of variability at one extreme or almost species-distinct varietal clusters at the other. Cultivated peanut varieties appear to fall somewhere between these two extremes, different enough to be interesting yet similar enough to be exasperating.

In his study of the origin of cultivated peanuts, Dubard (23) suggested that the forms which were transported from Brazil to the west coast of

Africa were varietally distinct and more primitive than those peanuts of Peru which had found their way into Mexico in pre-Columbian times, and later travelled from Peru to the islands of the Pacific, East Asia, and as far as Madagascar. The latter forms reached Spain via France from Mexico. The varietal terms "African" and "Asian" arose from this post-Columbian distribution of cultivated peanut forms. There can be little question but that the peanut known in the United States as "Valencia" is the Peruvian-Mexican-Asian-Spanish (Archbishop of Valence) form.

Chevalier (16) noted that the upright and prostrate habits of peanuts were insufficient grounds for establishing subspecies.

Some 40 varieties were listed by Hayes (30) who gave their countries of origin. His classification divided *A. hypogaea* into runner and bunch varieties. Four groups of varieties were separated under his bunch group on the basis of such characters as corolla color, seed-coat color, hairiness, etc. Six runner groups were similarly separated on the basis of such superficial characters.

John and Seshadri (40) went so far as to give a Latin description of a variety "*gigantea*" which they had discovered among the segregating progeny following a cross.

Hull (36) stated that the peanuts which he used in a genetic study fell into three groups, runner, Spanish and Valencia.

Clos (17) used the following ten characteristics in classifying the types of peanuts grown in Argentina: Carriage of the plants, color of the seed coats, number of seeds per fruit, size of fruits, constriction of the fruits, elevation of fruit venation, color of the stalk, pubescence of the stalk, weight of the seeds, and venation of the seeds. Like Hayes, Clos divided cultivated peanuts into two main groups, upright and prostrate. Then by means of the characters listed above he isolated eleven upright types and four prostrate types known in Argentina.

More recently Bouffil (13) has stated that the only characters which are of any value in varietal classification are (1) the carriage of the plant, and (2) the presence or absence of a rest period in the seeds. He further states that characters ordinarily utilized in the classification of plants are of no value in separating varieties of peanuts. He disagrees with Chevalier (16) and separates *A. hypogaea* into two subspecies on the basis of whether the plans are prostrate or upright. His classification follows:

A. Plants prostrate
- *A. hypogaea* subsp. *africana*
  - (a) Early maturity, immediate germination: var. *praecox*
  - (b) Late maturity, delayed germination: var. *tarda*

AA. Plants erect
A. hypogaea subsp. *asiatica*
(a) var. *praecox*
(b) var. *tarda*

When a large collection of types of peanuts are brought together, or segregating progenies of varietal crosses are observed, one of their outstanding features is the fact that any ordinarily accepted agronomic variety has its own cluster of seed sizes; seed-coat colors; shell thicknesses, reticulations, and constrictions; plant types; leaf colors, textures, margins; and many other characters.

Before Europeans brought the varieties together and began artificial crossing, self-pollination and geographic isolation led, in pre-Columbian times, to the formation of rather distinct varietal groups. The authors mentioned above, with the exception of Hull, have not produced a satisfactory classification nor have they agreed with one another. Everyone who has worked with peanuts can recognize the three varieties known in the United States as Virginia, Spanish, and Valencia. If the agriculturist can identify these peanut varieties at a glance, there must be some obvious morphological features which distinguish them.

Richter (59) correctly understood the morphology of the peanut inflorescence and properly described it, but French, English, and American workers have rarely referred to his excellent work. Richter specified in clear morphological terms just where the inflorescences are produced, but he did not provide illustrations. Cultivated peanuts apparently never produce flowers on the main axes of the plant, but on some more or less well-developed axillary reproductive branch. The flowers, contrary to scientific and popular opinion, never arise from the axils of foliage leaves. It is the reproductive branch or inflorescence which thus arises. The inflorescences produce scale leaves similar to cataphylls and it is in the axils of these that the subsequent branches of the inflorescences bearing the flowers are produced. Cataphylls (unless one calls cotyledons cataphylls) do not occur on the main stem axis.

Virginia peanuts differ from Spanish and Valencia peanuts in seldom, if ever, producing an inflorescence from the first cataphyll of a lateral branch of any order. This character is common to all forms of Virginia peanuts. They may have large, medium, or small seed, and thick, intermediate, or thin shells. They may be prostrate or upright but in the basic features which lead a farmer to say, "Virginia Runner," "Virginia Bunch" or "some kind of a Virginia," they are similar and may be distinguished from other peanuts. On the other hand, Spanish and Valencia peanuts always produce inflorescences in the first cataphylls of secondary

and higher order branches. This fact, in addition to the extreme reduction of the first internode of most of the lateral branches, so that in second-order branches the first cataphyll may be closely appressed to the main stem, leads to the erroneous impression that twin buds occur in the leaf axils on the main stem axis.

A botanical key to the varietal groups of peanuts follows:

A. Lateral buds of the central axis all vegetative. First cataphyllar node of n + 1 order branches vegetative; second occasionally reproductive.*
  (a) n + 2 order branches occur as pairs of vegetative branches alternating with pairs of reproductive branches. .... *Virginia*

AA. Lateral buds of the central axis vegetative or reproductive. First and second cataphyllar nodes of n + 1 order branches reproductive.
  (a) n + 2 order branches irregularly reproductive and vegetative. Pods two to three seeded. .... *Spanish*
  (aa) n + 2 order branches all reproductive or sometimes mostly vegetative distal to the 6th-8th node. n + 3 order branches all reproductive. Pods 3-6 seeded. .... *Valencia*

* See previous sections, *Vegetative Structure of the Mature Plant: Stem;* and *Reproductive Morphology:* inflorescence.

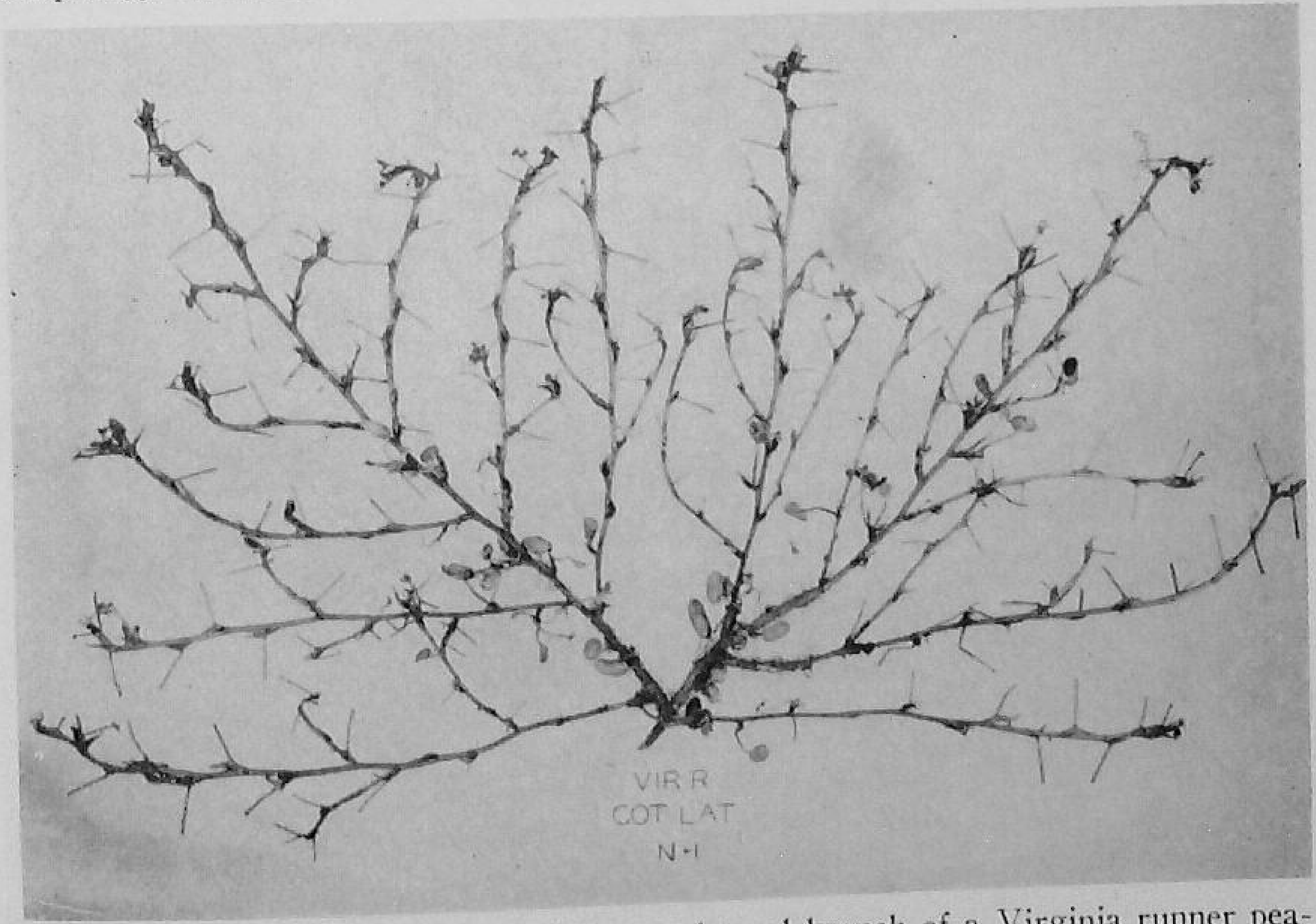


Figure 18.—An *n + 1* order, cotyledonary lateral branch of a Virginia runner peanut. Two *n + 2* vegetative branches arise from the first two nodes of this branch, two *n + 2* reproductive branches from the next two nodes, two *n + 2* vegetative branches from the next, two *n + 2* reproductive from the next . . . The same pattern of alternating pairs of nodes appears on each successive order (*n + 2, n + 3, n + 4*) of vegetative branches, so that the occurrence of reproductive branches does not limit the extent of the branching system. The branching order may but usually does not exceed *n + 4* vegetative and *n + 5* reproductive in Virginia runners.

1. *Virginia* (figures 18, 19, 20).—Plants copiously branched, consisting as in *Valencia* and *Spanish* of four or more principal lateral branches. Laterals frequently far exceeding the main stem in length, though of approximately the same length in some erect types. Main stem nodes all vegetative. All lateral branches vegetative in the first node and mostly vegetative in the second node. Nodes of the lateral branches of all orders generally occur in alternating pairs of two vegetative and two reproductive. Upper internodes 20-25 mm. in length. The main stem usually produces many lateral branches in erect types or few in prostrate types. Leaves and leaflet smaller, leaflets more firm and pointed elliptic than in the two following; dark, glaucous green. Stems moderate in size less coarse than in following, erect or prostrate. Fruits from 2-5 cm. in length 1-3 seeded, mostly 2 seeded. Shells thick or thin, reticulation usually prominent. Constrictions between seeds apparent to marked. Seeds 0.5 gm.-2.0 gms., elongated and pointed, usually germinating only after 30-

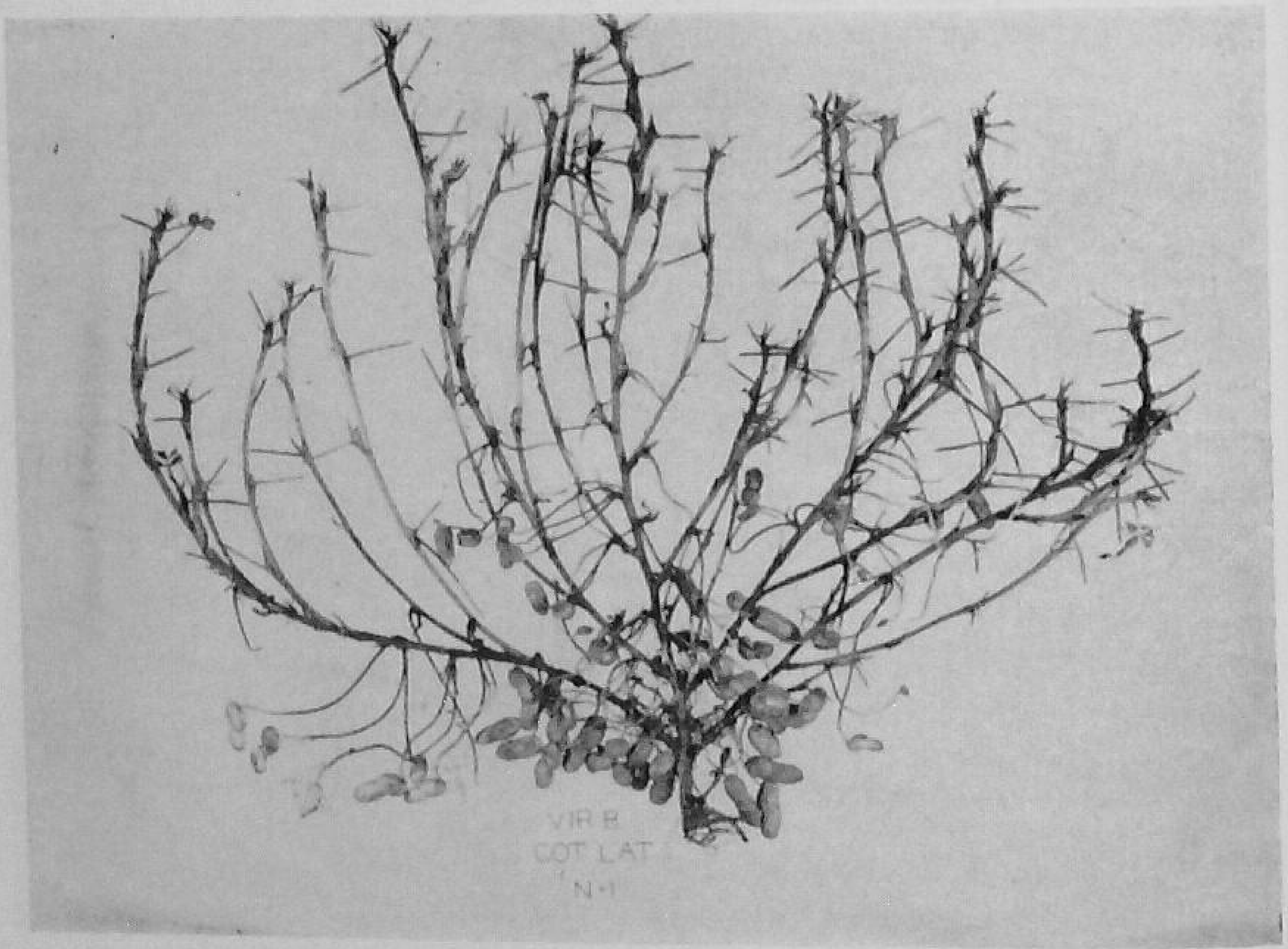


Figure 19.—An $n + 1$ order, cotyledonary lateral branch of a Virginia bunch peanut. The same succession of two $n + 2$ vegetative branches and two $n + 2$ reproductive branches occurs as is found in Virginia runner. The branching pattern of the higher order $(n + 2, n + 3)$ vegetatives also consists of alternating pairs of vegetative and reproductive branches. As in Virginia runner, the extent of the branching order is indeterminate, but in Virginia bunch it usually does not exceed $n + 3$ V and $n + 4$ R.

360 days "rest" period, usually pink, sometimes tan, rose, wine, red or variegated red and white. Moderately resistant to cercospora leaf spot.

2. *Spanish* (figures 21, 22).—Plants moderately branched, consisting of four or more main lateral branches arising as in *Valencia*. Main stem and laterals usually of approximately equal lengths. Nodes of the main stem above the principal laterals vegetative and reproductive; nodes of laterals irregularly vegetative and reproductive, usually continuously reproductive for as many as six nodes; frequently, however, vegetative at nodes 3 and 4 on the cotyledonary laterals. First two nodes of lateral branches reproductive. Inflorescences unbranched. Leaves and leaflets similar to Valencia though usually somewhat smaller and paler green. Upper internodes 20-30 mm. in length. Stems moderate in size, usually

Figure 20.—A Virginia bunch peanut in profile.

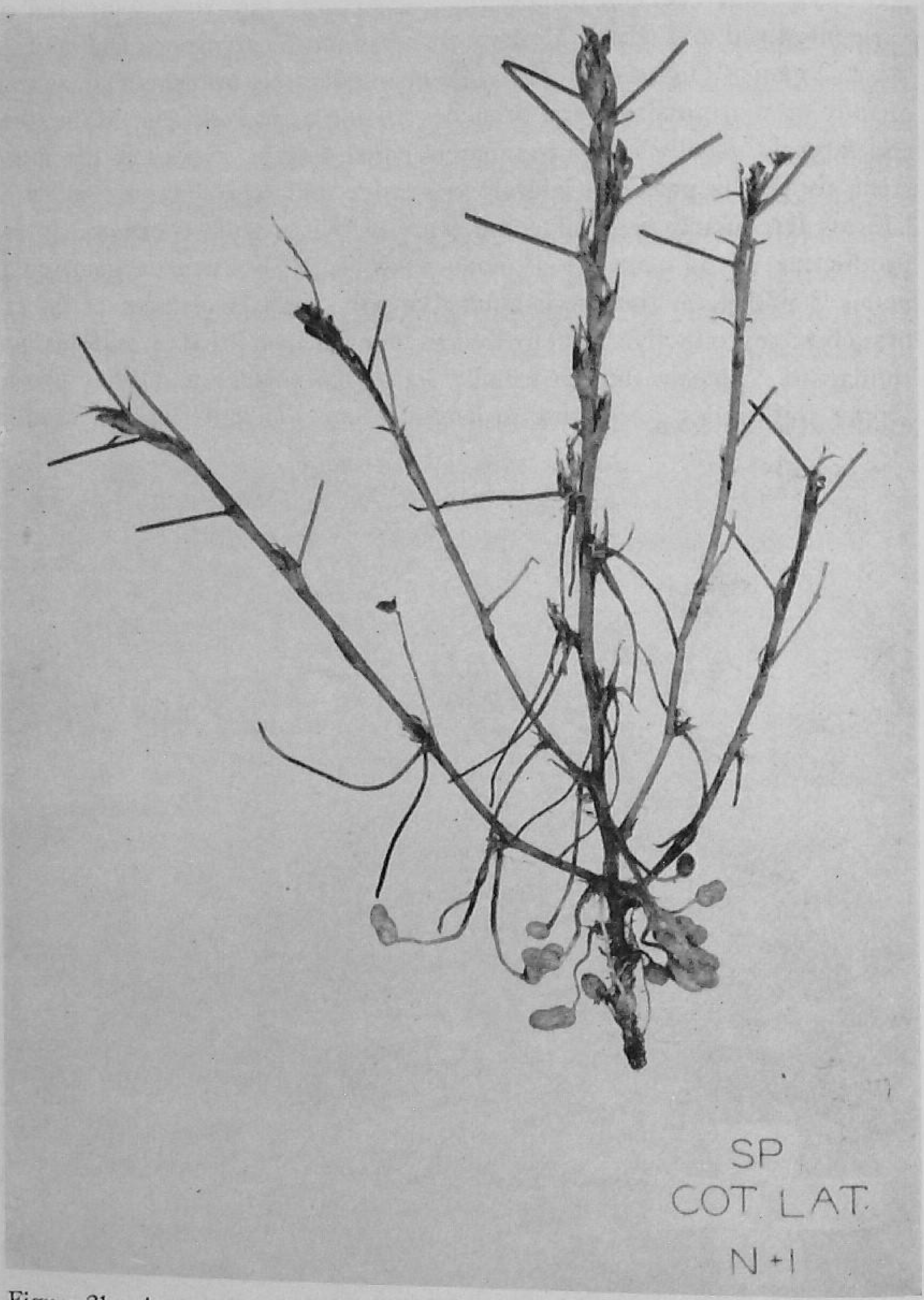


Figure 21.—An $n + 1$ order, cotyledonary lateral branch of a Spanish peanut. The $n + 2$ vegetative branches occur sporadically and the $n + 2$ reproductive branches arise at the remaining nodes. The upper nodes are all reproductive as are all the nodes of the $n + 2$ vegetative branches. This is in contrast to the regularly paired situation present in the Virginia variety. As in Valencia, the branching system is determinate, ending with the production of $n + 2$ V which produce $n + 3$ R

smaller than in Valencia, mostly erect, green. Fruits variable in size, 1-3 cm., usually about 2 cm.; 1-3 seeded, mostly 2 seeded, clustered near the base of the main stem. Shells thin, prominently veined; beak small or lacking. Constriction moderate to pronounced. Seeds variable, spherical to rounded elliptic, sometimes red or pink, usually flesh, sometimes white, 0.2 gm.-0.5 gm., germinating immediately upon maturity. Highly susceptible to cercospora leaf spot.

3. *Valencia* (figures 23, 24).—Plants sparsely branched, consisting usually of four (sometimes six) main lateral branches, one from each cotyledonary axil and one from each of the first two foliage leaf axils of the main stem. Main stem and laterals usually of approximately equal lengths. Nodes of the main axis above the principal laterals mostly re-

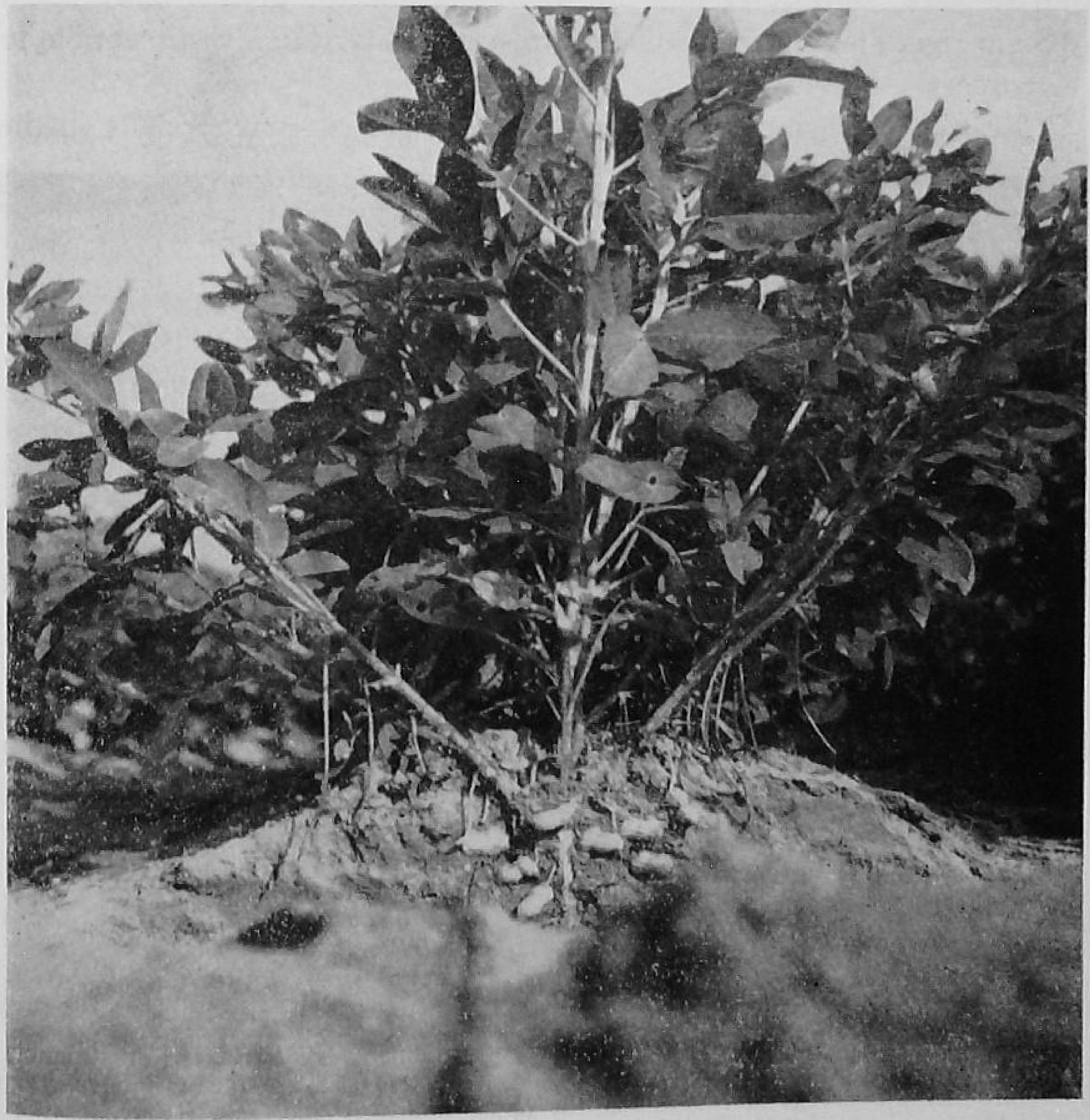


Figure 22.—A Spanish peanut in profile.

productive. Nodes of the n + 1 laterals often continuously reproductive for eight or more nodes. Vegetative branches occasional, rarely more frequent on the n + 1 laterals and main stem axis. Highest order of vegetative branching, n + 2, frequently only n + 1. First two nodes of lateral branches reproductive. Inflorescence sometimes branched. Leaves and leaflets large. Upper internodes 30-35 mm. in length. Stems large, laterals sometimes 7.5 mm. in diameter, coarse, mostly erect, occasionally lax; frequently purple, but sometimes green. Fruits variable in size 2-6 cm. long; 1-6 seeded, mostly 3-4 seeded. Shells variable, usually moderately thick with only slightly raised venation; sometimes thin with prominent venation and beaked; constrictions between the seeds slight, occasionally more evident. Seeds variable, spherical or elongated, usually red or purple-black, sometimes pink or flesh; 0.2 gm.-0.8 gm., usually about 0.5 gm.; germinating immediately upon maturity. Highly susceptible to cercospora leaf spot.

Beattie (9) lists the following varieties grown commercially in the

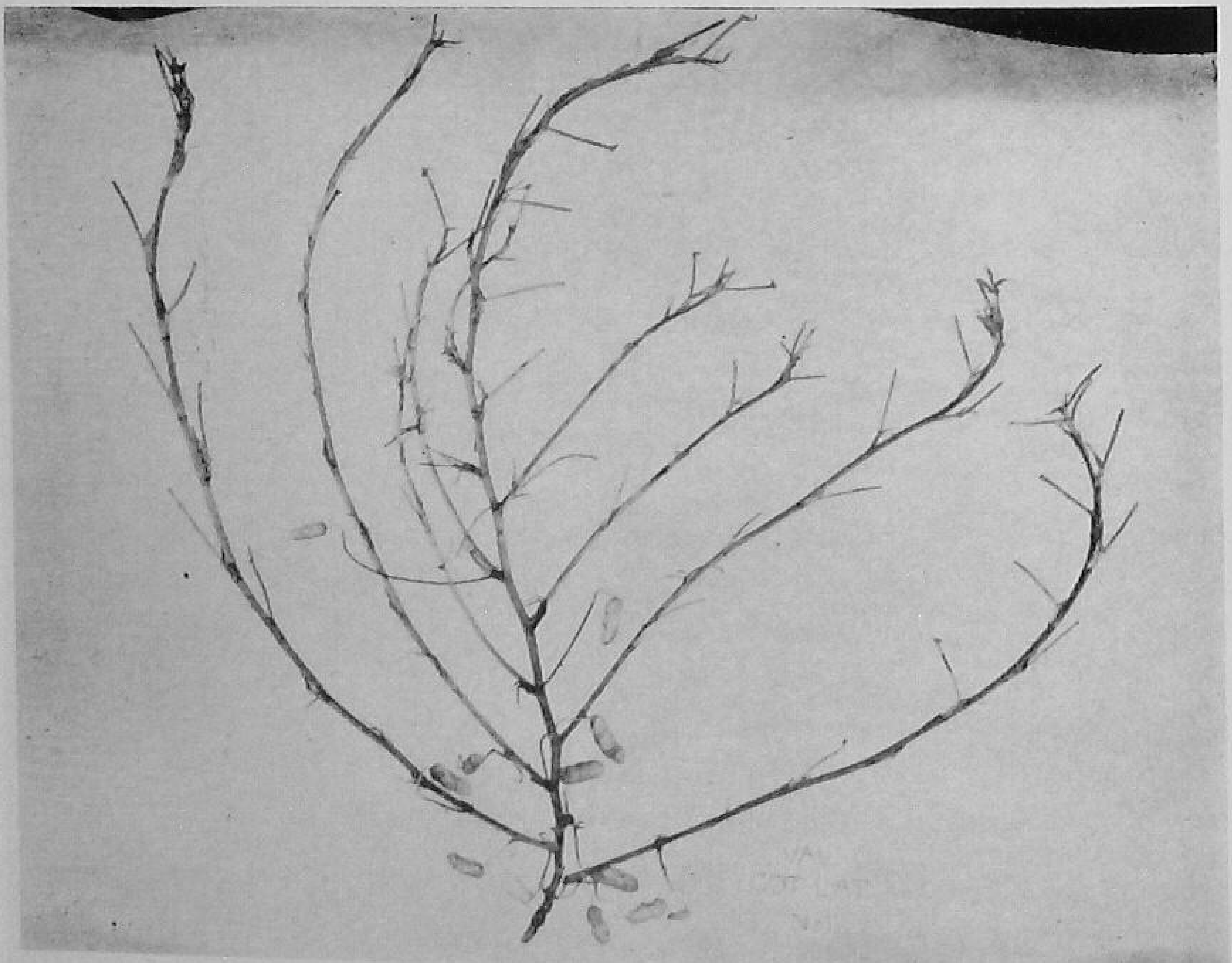


Figure 23.—An $n + 1$ order, cotyledonary lateral branch of one form of Valencia. The $n + 1$ branch produces $n + 2$ reproductives at its lowest nodes, then several $n + 2$ vegetatives, finally the upper nodes produce $n + 2$ reproductives. All the nodes of the $n + 2$ vegetatives bear $n + 3$ reproductives which terminate the branching system.

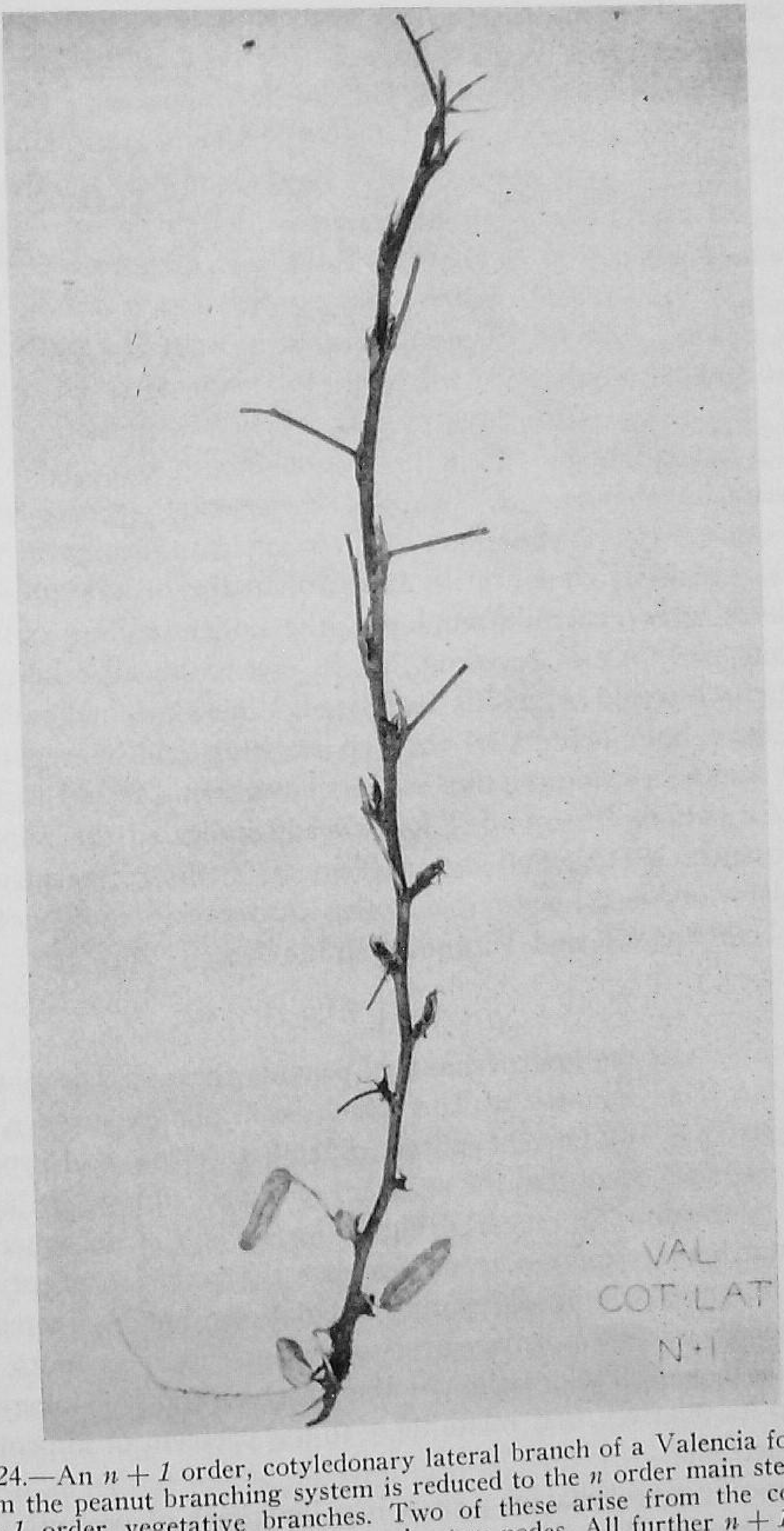


Figure 24.—An $n + 1$ order, cotyledonary lateral branch of a Valencia form. In this form the peanut branching system is reduced to the n order main stem and four $n + 1$ order vegetative branches. Two of these arise from the cotyledonary node and two from the next two main stem nodes. All further $n + 1$ nodes and all $n + 2$ nodes bear reproductive branches which terminate this branching system.

United States. They are shown here as they could occur if classified by the foregoing system.

1. Virginia Runner	— Prostrate	
2. Jumbo Runner	— ″	
3. N.C. or Wilmington Runner	— ″	— Virginia
4. African	— ″	
5. Virginia Bunch	— Erect	
6. Spanish	— Erect	
7. Improved Spanish	— ″	— Spanish
8. Small Spanish	— ″	
9. Tennessee White	— ″	
10. Tennessee Red	— ″	— Valencia
11. Valencia	— ″	

If this scheme of classification based upon the orders and patterns of branching were generally employed, the understanding of reported experiments, not only in breeding, but in essentially all other types of peanut research would be greatly facilitated. Where original varietal distinctions have been obliterated through crossing and segregation, the parentage and a brief description in the above terms would furnish the needed information. Prevot (54) has already indicated the relationship between branching habit and the problem of fertilizer treatments with peanuts. It is obvious, however, that this relationship could not be the same for both Spanish and Virginia peanuts.

GENETICS AND BREEDING

The problem of the improvement of peanuts through selection is not a simple one. The peanut is a plant which is, in our experience, for all practical purposes 100 percent inbred, difficult to cross, and productive of so few seeds per plant that the recovery of improved types in small segregating populations is rendered highly improbable. Consequently today's peanut breeder must not only increase the precision of estimating genetic differences within segregating populations, but also must overcome the sterility barriers between the various species of peanuts, gather fundamental biological information on the structure and physiology of the peanut and its relatives, and relate these to the problem of improvement through selection.

The reproductive behavior (*i.e.* self-pollination) of peanuts is such that new forms tend to be preserved and isolated from one another. Nevertheless there has been hardly a breeder from the time of Van der

Stok (74) to the present, who has not been able to isolate distinct strains from within varieties. The question of selection within varieties as opposed to selection within hybrid populations has claimed the attention of peanut breeders. Men with long experience have maintained that pure lines of peanuts tend to break down if selection pressure is relaxed. The instability of the pure lines may have arisen from (1) accidental seed mixture (2) natural outcrossing, or (3) chromosomal instability. The first possibility need not be discussed. According to Kushman and Beattie (42) natural hybridization occurs with low but significant frequency. In experiments designed to clarify this point numerous cases in which crossing had occurred between Spanish and Valencia peanuts were studied. The observed segregation of seed coat colors followed the expected pattern. Three years of work demonstrated a small but definite amount of natural crossing. Critical experiments of this nature have not been conductive by other workers so this is the only reliable published account. In contrast, the present senior author has observed the consistent uniformity of hundreds of F_5 and F_6 plant progenies. These have included many diverse families from experimental crosses grown side by side. If further experimental evidence confirms the opinion that pure lines of peanuts are unstable in the absence of selection pressure, this will be in harmony with the known behavior of peanut chromosomes. Husted (38) observed multivalent chromosome associations at first meiotic metaphase and concluded *A. hypogaea* was a tetraploid. Mendes (44) confirmed this in 1947. The number of chromosomes in cultivated peanuts is $2n =$ 40 while some of the wild species examined have $2n = 20$, observations which the writers have also made. The irregularities reported by Husted (38) provide ample basis for predicting sporadic segregation from cultivated strains.

Notwithstanding the fact that peanuts were subjected to genetic study by Van der Stok (74) as early as 1910, only limited progress has been made in the improvement of peanuts through breeding. With the advent of World War I interest in peanuts as a source of vegetable oil stimulated peanut-breeding activity. Thus in the United States reports of breeding work began to appear about 1918, Beattie, private correspondence). Although the U.S. Department of Agriculture continued its efforts through the third decade of this century, active work at the various State experiment stations did not begin until near its end. Breeding programs have been reported as starting in Georgia in 1931, in Florida in 1928, in North Carolina in 1929. During these years most of the work in Virginia, North Carolina and South Carolina consisted of making individual plant selec-

tions from among existing stocks of peanuts. The programs in both Florida and Georgia appear to have developed from selection within hybrid populations from varietal crosses. Meanwhile reports from India (1), the Philippines (24, 49, 56, 61, 62), the Dutch East Indies (12), French West Africa (16) and elsewhere continued to reach this country. Breeding programs have been in existence in the U.S. Department of Agriculture for 30 years, in State experiment stations for 20 years, and for similar lengths of time in various foreign countries. At present some effort is being expended toward peanut improvement through selection in nearly all warm temperate and tropical countries.

Despite the great effort put forth in various countries of the world little success has been achieved in peanut breeding. The products of these researches are not, by and large, the plants which fill the commercial fields; or if they are they have not raised to any degree the average output of the areas where released. For example, the average production per acre in the Virginia-Carolina area continues at about 1,100 pounds per acre, notwithstanding the sporadic "improvement" announcements of the past 30 years. During these same years, while the spring wheat industry of the United States and Canada was saved by breeding and pathological researches, and corn production was revolutionized by breeding, the "improved" selections of the peanut breeder have continued to maintain the low State average yields (figure 25).

As yet we can only surmise the biological explanation of Bouffil's (13) statement that the hybridization of peanuts has been attempted but that up to the present no positive results have been obtained; or of Darlington's (20) declaration, in reviewing Mendes' (44) cytological work, that perhaps this will open the way to improved varieties from interspecific crosses in this plant, which hitherto has been so unresponsive to improvement through the ordinary methods of cross-pollination and selection.

While there is no doubt that peanuts are difficult material, the independent and isolated attempts of the various workers on the problem have been a contributing factor to the slow progress made in this field. It is misleading to take too seriously the comparison of 30 years' research on wheat and corn with the unconnected reports on the peanut over the same period. Few cross-references exist in the literature on peanuts, each man having gone his independent way. Thus there have resulted needless repetitions of effort and the consequent elementary nature of experiments evident in all the literature. The combination of the lack of knowledge, or the possession of erroneous information on the biological nature of pea-

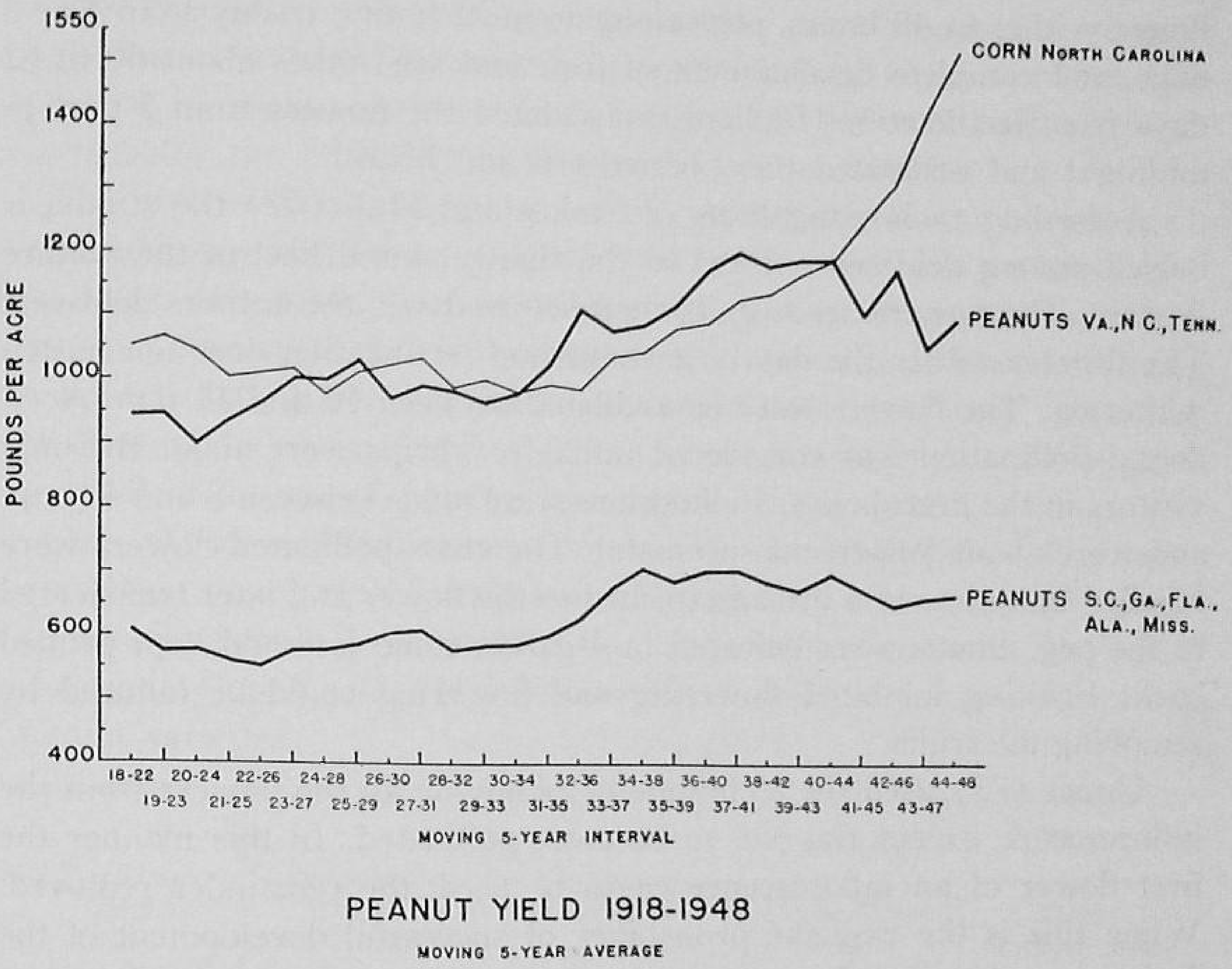


Figure 25.—Thirty years of peanut production in the southeastern United States. The light line shows corn production in North Carolina during the same period.

nuts with the disparate nature of the breeding experiments conducted, is sufficient in itself to render success improbable.

In reporting the published works on peanut breeding and genetics we have been unable to unfold a sequence of events or to build a coordinated body of knowledge culminating in recent advanced studies logically derived from the results of previous experiments. Instead we have attempted to preserve the mosaic of unrelated patterns and have organized them only to the extent of presenting first, a summary of breeding *techniques;* second, *inheritance studies;* third, *disease resistance;* and fourth, *breeding.*

Techniques

(a) Cross-pollination

Badami (1) made the following observations with respect to the technique of crossing peanuts: The pollen sacs burst about sunrise on warm days, fertilization is completed within 30 hrs,*, flowers droop in 24

* It is known to occur in 12-16 hrs; see *"Reproductive Morphology".*

hours, wither in 48 hours, pegs elongate in 72 hours, visibly so in 4 or 5 days, and complete development of fruit and seed takes about 60 to 62 days from fertilization. Badami emasculated the flowers from 5 p.m. to midnight and pollinated them between 6 and 7 a.m.

According to investigations of Stokes and Hull (69) the stigma is buried among dehisced anthers in the tightly closed keel of the mature flowers. The flowers are fully opened before dawn, the anthers dehisced. The flowers wither the day of anthesis and fertilization does not hasten withering. The flowers were emasculated between 10 and 11 p.m. Accidental pollination was considered unlikely. Thrips were about the only visitors in the greenhouse. Pollinations were made between 8 and 10 a.m. and were about 50 percent successful. The cross-pollinated flowers were labelled by means of a thread attached to the flower and later transferred to the peg. Plants were cultured in 4-gallon stone jars and kept pruned back. Fruiting inhibited flowering and flowering could be induced by removing the fruits.

Umen (73) used the technique of removing all the flowers from the inflorescence except the one to be cross-pollinated. In this manner the first flower of an inflorescence could be used, the remainder removed. When this is the case the probability of successful development of the fruit is greater and the opportunity for mistaken identity of the cross almost eliminated. Emasculation was done with forceps between the hours of 2 and 8 p.m. the day before the flowers were to open. Bagging the emasculated flowers was found to be unnecessary. The pollinations were made early the next day. The plants were grown in pots.

Patel *et al.* (48) emasculated the buds between 5 and 6 p.m. The result was checked by a hand lens. Pollination was effected between 7 and 8 a.m. Ten to 30 percent of the pollinations were successful. The flowers were not bagged. The plants were grown in large pots. The crosses were marked by different colored threads. After 4 to 5 days the thread was transferred to the peg.

(b) Vegetative propagation

Many things coordinate the forces of adversity on the would-be peanut breeder. Only a few hours are available for emasculation each day and these fall at the rather inconvenient time when ordinary men are preparing to go to bed. It should be added that each emasculation consumes several minutes so that the total for an evening's work is rather small. Some alleviation of this difficulty is obtained by the propagation of peanuts from cuttings. The number of plants grown from each hybrid seed can be much increased by use of this technique. Sufficient work

has now been done with cuttings to permit the employment of F_1 testing should this seem to be desirable in peanut breeding. Gregory conducted replicated F_1 trials of peanuts from cuttings in 1945 with sufficient success to show the reliability of this method of propagation.

The first work recording the use of cuttings as a tool in varietal experimentation with peanuts was reported by Guerrero (28) who, on the Island of Guam, made the first recorded comparison of yields of nuts and forage per acre of peanuts from cuttings and from seed. It is obvious from the limited data given that the experimental error was very large. No further work has been reported from this source. Rodrigo (61) became interested in the use of cuttings as a means of propagation to escape the problem of seed deterioration common to the Philippines. His seed germination averaged 94.7 percent and 89.7 percent of the cuttings rooted. The following table gives some of the comparative figures on developed pods, undeveloped pods, and pegs without pods at harvest for three different varieties:

Variety Name	*Propagating Materials*	*Number of:*		
		Developed Pods	*Undeveloped Pods*	*Stipes Without Pods*
Kinorales	seed	26.10 ± 1.15	11.90 ± 0.67	20.40 ± 1.59
Kinorales	cutting	23.30 ± 0.89	13.90 ± 0.64	33.10 ± 2.04
Lemery	seed	19.20 ± 1.21	10.70 ± 0.92	15.00 ± 2.11
Lemery	cutting	18.00 ± 0.96	8.60 ± 0.70	27.00 ± 2.32
Valencia	seed	23.40 ± 0.94	13.90 ± 0.99	18.30 ± 0.94
Valencia	cutting	14.40 ± 0.73	10.10 ± 0.74	13.70 ± 0.87

Rodrigo pursued the problem of yield from cuttings further. Cuttings were taken from three varieties when the plants were 2, 3, and 4 months old. This experiment was badly hit by ants and drought so that no comparison could be made between seed and cuttings; of the cuttings, however, the 3-month-old plant cuttings gave the highest percentage rooting while the 2-month-old plant cuttings gave the greatest production of forage and seed.

Gregory (26) found that rapidly growing plants just prior to flowering produced highly successful cuttings. It should be noted, however, that the total number of cuttings per plant under these circumstances is much smaller than from older flowering specimens.

Harvey and Schultz (29) compared the yields of plants from cuttings of main stems and laterals with the yields of plants from seed. It will be recalled that the peanut produces a single main stem, primary laterals,

and other lateral branches. The test was planted in a split plot design where the sources of plants were the subplots (main stem, lateral branch, or seed) and the three varieties used were the whole plots. No significant differences in yield were found between the two sources of cuttings. The yields of plants from seed were significantly less than those of plants from main stem cuttings but not less than those from lateral branch cuttings. The seed were planted the same day the rooted cuttings were placed in the field, but the plants from seed may not have been strictly comparable in developmental stage to the cuttings. The following table shows the results obtained:

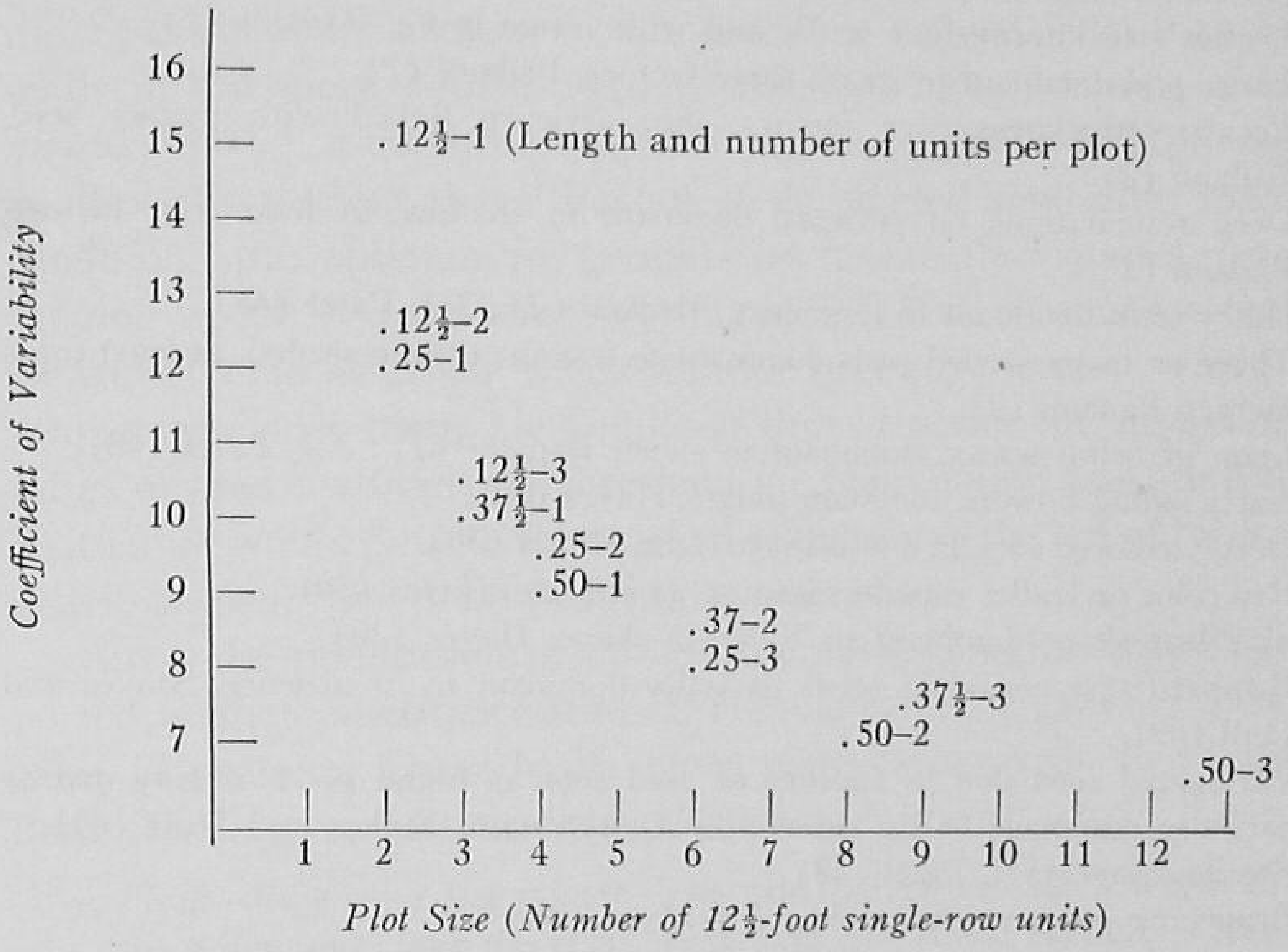
Yields of Peanuts in Pounds/Acre

	Lateral branch	*Main stem*	*Seed*	*Average for strain*
N. C. Sel. 32	1,237.8	1,514.4	890.0	1,193.9
Martin Co. Runner	1,002.5	1,281.6	1,173.9	1,132.4
Spanish 2B	1,127.6	1,026.7	1,028.1	1,101.0
Av. for source of plants	1,122.3	1,274.6	1,030.0	

(c) Field plot size

Beattie *et al.* (8) concluded after some years' experience that the optimum plot size for testing varietal differences in peanuts was a single 100-foot row or five to six 20-foot rows. Robinson et al. (60) investigated optimum plot size from uniformity data. Their conclusions, briefly summarized below, are perhaps the most reliable information to be had on this subject. The uniformity data were handled in terms of decreasing coefficients of variation with increasing plot size. The following diagram gives the pertinent results:

Average Coefficients of Variability for Different Plot Dimensions Where Replications Consist of 6 Assumed Varieties.



Inheritance Studies

Van der Stok (74) reported that red testa and light red testa segregated three dark red to one light red in the F_2. Badami, Hayes, Hull, Patel *et al.*, and Stokes and Hull (1, 30, 36, 48, 69) have studied the inheritance of various characters in the peanut. Hull (36) summarizes the genetic results which had been published by 1937. His summary follows:*

"1. Red seed dominant to russet or tan (3:1), Van der Stok (74), Badami (2), Stokes and Hull (69), Hayes (30). Four colors purple, red, rose, and white, with genes Pp,Rdrd, R_1r_1, R_2r_2, Patel (48).
2. Prostrate habit dominant to erect, two factors, Badami (2); (15:1) Hayes (30); duplicate genes, Patel, (48).
3. Chlorophyll; three factors with triple dominant dark green and triple recessive albino, Badami (2); two genes, Patel (48).
4. Dark red stem dominant to light red (3:1), Hayes (30). Violet tinge dominant, appears to be associated with hardiness, Badami (2). Purple stem, duplicate genes, Patel (48).
5. Long seed dominant to short (15:1), Hayes (30).
6. Fertile dominant to sterile, complementary (15:1), Hayes (30).
7. Normal leaf dominant to crinkled leaf, complementary (15:1), Hayes (30).

* This is quoted exactly except that the present writers have altered the reference numbers so that they now correspond to the references cited at the end of this chapter.

8. Leaf rachis presence dominant to absence, complementary (15:1), Hayes (30).
9. No constriction on pods, double dominant, two factors, Badami (2).
10. Leaflet size intermediate in F_1 and wide range in F_2, Badami (2).
11. Large pod dominant to small, three factors, Badami (2).
12. Pericarp thickness, five factors, thin pericarp linked with pygmy seed, Badami (2).
13. Deep reticulations on pericarp dominant to shallow, at least four factors, Badami (2).
14. Hairy stem dominant to less hairy, Badami (2); 3:1, Patel (48).
15. Three or many-seeded pods dominant to less than three-seeded, at least three factors, Badami (2).
16. Long growing season dominant to short, Badami (2); 3:1, Patel (48).
17. Early fading flowers dominant to late, Hayes (30).
18. Deeply colored corolla dominant to light, Hayes (30).
19. Red color on leaflet vein dominant to its absence, Hayes (30).
20. Sine leaf shape dominant to Valencia shape, Hayes (30).
21. Required rest period of seeds partially dominant to its absence, Stokes and Hull (69).
22. Variegated seed due to rupture of seed coat as found in *A. namby quarae* partially dominant to its absence in *A. hypogaea*, Stokes and Hull (69).
23. Sterile dwarf, 15:1, Patel (48).
24. Branching over non-branching, 3:1, Patel (48)."

Hull's own work was chiefly directed toward analyzing the genetic behavior of dormancy in peanut seeds. In addition, however, he reported the following results on other characters:

1. In crosses of Spanish and Runner peanuts long by short seeds were intermediate in the hybrid. The results indicated that seed shape was largely controlled by physiological maternal influence rather than by embryo genotype.
2. Russet seed coat of Runner peanuts dominant to tan in Spanish.
3. Yellow seedlings from certain crosses behaved as full recessives in a duplicate gene complex with green fully dominant. The assignment of genetic formulae with respect to this character cuts across some interesting taxonomic lines, for Hull states that the following genetic formulae and varietal association was indicated from his study of this character: $L_1L_1l_2l_2$ (Spanish) $L_1l_1l_2l_2$ (Runner group and *A. nambyquarae* and $L_1L_1L_2L_2$ (Valencia and *A. Rasteiro**.)
4. Valencia plant type was found in the progenies of several crosses of Spanish x runner. It behaved as a recessive set of duplicate genes where each parent carried alternate recessive and dominant pairs.
5. Male sterile brachytic dwarf appeared in the progeny of Virginia Runner x Tennessee Red and behaved as a simple recessive.
6. The regressions of twenty-two separate characters as dependent variables, and rest period of seeds, seed shape, seed coat color, yellow seedlings, and Valencia plant type as independent variables were analyzed. No significant regressions were found.

* *A. Rasteiro* = a form of *A. hypogaea.*

Hull measured the rest period in peanut seeds in terms of average time to emergence with seeds planted as soon as possible after harvest. In the Spanish and Valencia groups this time ranged from 9 to 50 days, while in the more dormant group which includes runners, *A. nambyquarae,* and *A. Rasteiro* it ranged from 110 to 210 days. Hull makes the additional statement that, "Peanut seeds planted soon after maturity in conditions near optimum for germination frequently required rest periods ranging up to 2 years before germination." Hull assumed a multigenic control of what he called "seed condition necessary to rest" with a normal frequency distribution. He supposed that at about the midpoint of the range of seed condition the threshold for germination was attained. Such a situation would explain the marked skewness to the left of his frequency distribution of days from planting to emergence.

Since the publication of Hull's summary, Higgins (31, 32) has reported further inheritance studies. He analyzed the genetics of seed coat color in peanuts. Three basic colors were recognized: Red, white, and flesh. These were further characterized as follows:

1. *Flesh*—Base color is a salmon flesh, pale to dark, reddish lilac markings about the hilum and along the veins, sometimes spreading. Varieties: Spanish, N.C. Runner (African), Virginia Runner, Virginia Bunch.
2. *Red*—This color also includes salmon lilac, various purples, and slate violet.
3. *White*—Philippine White and Pearl are greenish white to lilac white which weathers to yellow white.

Red x Flesh	Flesh x White (Philippine White)
F_1 all Red	F_1 all Flesh
F_2 3 Red : 1 Flesh	F_2 15 Flesh : 1 White
	White (Pearl) x Red
	F_1 all Red
	F_2 12 Red : 3 Flesh : 1 White
	White (Pearl) x White (Philippine White)
	F_1 all Red
	F_2 Red, Flesh, and White

The numbers were too small in the white x white progeny to establish the genetic basis with certainty, but the following suggested formulae appear to explain the results obtained:

Pearl	$RRF_1F_1F_2F_2$	$d_1d_1d_2d_2$
Phil. White	$rrf_1f_1f_2f_2$	$D_1D_1D_2D_2$

It is obvious that there are at least duplicate factors for flesh, an additional factor which produces red in the presence of both flesh factors, and two factors for color development, the absence of either of which results in white.

Disease Resistance

Varietal resistance of peanuts to sclerotium wilt or southern root rot has been reported by Reyes (56). From experiments conducted in the Philippines Reyes concluded: "Different varieties of peanuts grown in an infected field showed varying degrees of infection. Wilting ranging from 31.3 to 50.7 per cent of the plants was noted by actual counts.

"Varieties used in field inoculation tests showed susceptibility to peanut wilt in the descending order as follows: (a) Valencia; (b) Macapno; (c) Georgia Red; (d) White Improved Spanish; (f) Biit; (g) Cagayan No. 1; (h) San José No. 3; (i) Vigan Lupog; (j) Tirik; (k) Tai-tau; (l) Virginia Jumbo; and (m) Virginia Jumbo (a). The least infected varieties were Virginia Jumbo (a), Virginia Jumbo, and Tai-tau while Valencia and Macapno were the most seriously infected."

Bolhuis (12) stated that *A. Rasteiro*, *A. nambyquarae*, and Schwarz 21, a selection from native sources, were highly resistant to the slime disease (*Bacterium solanacearum*). Higgins (31) stated that resistance to each of the two leaf spotting fungi is inherited separately and suggested that a single factor is involved in each case. With respect to resistance to *Sclerotium rolfsii* this author stated that "most of our selections show a high degree of resistance." Reyes and Romasanta (57) reported variations in susceptibility among 16 different varieties to *Cercospora personata*. The intensity of infection was measured by leaf spot count from a duplicated trial. It was suggested that resistance to this disease might be attained through breeding.

Breeding

In 1910 Van der Stok began the breeding work with peanuts in the Netherlands East Indies. In 1938, Bolhuis gave the following as principal objectives in the breeding program: high yield, resistance to slime disease, erect foliage, large seeds, pods with more than two seeds, pods with slight constriction, and early ripening.

Badami (1) reported his initial hybridization results with peanuts in 1922 and in later annual reports from the Mysore Agricultural Department he has indicated the results of subsequent selection.

Patel *et. al.* (48) reported in 1936 that a breeding program had been been in progress in Madras for about 5 years. Approximately 100 varieties were grown in the two annual seasons, irrigated (February-June), "rain-fed" July-January).

The economic importance of peanuts, their world production, and a

short history of their cultivation in the U.S.S.R. were reported by Piroznikova (51). A description of the peanut, its types, varieties, and various characteristics were included. Extensive data are presented on variety trials in various regions of the U.S.S.R. The main aims stated for the breeding program for U.S.S.R. are earliness, drought resistance, disease resistance, high oil content, high protein content, and a production of a plant suitable for mechanical harvesting.

From Krasnodar, Umen (73) described the necessity of understanding the floral biology of the peanut. He stated that pure line selection started in 1926 had shown hybridization to be the only promising method for improvement of the peanut. To quote from the abstracting journal, "The method of pure line selection has not yielded very favorable results, especially in regard to resistance to Fusarium and hybridization is regarded as essential."

Selection for improved varieties of peanuts has been attempted in French West Africa since 1924. Many criteria for selection have been used without success. The morphological character of the pods and the weight per 100 seeds are now the principal characters selected. An extensive series of local strains collected from the native farms is grown at the central station. The selections are made but are subsequently increased in the locality where the original strain is grown and known to be adapted. Hybridization, either natural or artificial has yielded no results of consequence to the French West African program. Bouffil has not entirely abandoned the idea of the use of hybridization in peanut breeding but feels that the existing stocks of peanuts in French West Africa must first be purified.

In the United States, prior to 1930, the most extensive work on the breeding of peanuts was reported from Florida by Stokes and Hull (69). Single plants were selected from within an unselected variety, Florida Spanish, seven of which were tested for 8 years. Some showed increases over the original variety averaging 22.8 percent. It was concluded that plant-to-row selection produced high-yielding strains. No heterosis was observed in the various hybrids made.

Hull and Carver (37) have continued this work, and in 1936 published a summary of their breeding procedures. These workers concluded that the desired types could "hardly be obtained except by hybridization. . . . It has also appeared that large numbers of hybrids would be necessary to provide reasonable chances of obtaining the desirable types."

In Georgia an extensive breeding program is under way with a collection of varieties and strains with objectives to combine high yield,

quality, and oil of Spanish peanuts with disease resistance and nonsprouting of the bunch and runner types.

Results of variety yield trials for the years 1929, 1930, and 1931 were reported for the Holland, Virginia, Station by Beattie and Batten (7). This work was mainly directed toward increasing seed size. It was concluded that at least seven strains of Virginia type peanuts had inherent qualities of extra large seed.

In 1943, Batten (5) reported regarding the selection work at the Virginia Station: "The idea has been to develop a strain which would produce a high percentage of extra large kernels, 30 to 32 per ounce." The method of breeding has been confined to single hill selection without prior hybridization. The breeder stated that these selections behaved as pure lines. Batten (6) announced the release of two improved selections in 1945. The following table presents comparisons of these strains with a local commercial variety:

A Comparison of Yield and Grade of Two New Strains of Peanuts with a Commercial Variety

	Yield per Acre		*Meat*	*Extra Large*	*Kernels per ounce*	*Value per acre*
	Un-shelled	*Shelled*				
	Pounds	*Pounds*	*Per cent*	*Per cent*	*Number*	
Holland Jumbo.........	1945	1323	68.0	53	27	$182.44
Holland Virginia Runner.	2262	1698	75.0	27	37	$223.01
Commercial Jumbo.....	1695	1170	69.0	35	30	$157.30

Beattie, in private correspondence with one of the writers, stated: "*Peanut Improvement by Selection:* All this work has been carried on in cooperation with the State experiment stations in South Carolina, Virginia and Georgia. Dating back to 1918 and using individual hills as starting points, a number of high yielding, desirable quality strains have been developed. Spanish 18-38, Improved Spanish 2-B, and several strains of the large-seeded Virginia type are examples. Spanish 18-38 in particular has attained considerable commercial importance in most parts of the peanut-producing area."

Since 1945 the North Carolina Agricultural Experiment Station has been conducting research on the nature and extent of effective variation in populations from peanut hybrids. These experiments have been designed to indicate what, if any, breeding opportunities exist following the varietal crossing of peanuts. Preliminary results from this work show that

the total genetic variability in segregating populations of peanuts is large enough to make possible a selection advance beyond the mean of the original population. The prior conclusions of Umen and of Hull and Carver regarding the necessity of hybridization for the success of practical peanut breeding are fully supported by these data. The contrary conclusion reached by Bouffil suggests, however, that further exploration of the problem is justified.

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CHAPTER IV

PHYSIOLOGY AND MINERAL NUTRITION

By

HENRY C. HARRIS AND ROGER W. BLEDSOE[1]

The subject of this chapter is so broad in scope and so detailed that its treatment necessitates a limited discussion of any particular topic. In a limited space the authors have attempted to cover most contributions, although some foreign publications are inaccessible (23, 24, 25) and undoubtedly others have been omitted unavoidably since the data are presented in many languages.

Various aspects of plant physiology have advanced considerably in recent years, yet the application of that knowledge to the solution of problems associated with the peanut plant has been much neglected and little organized work has been done. After reviewing the work, the writers have the impression that greater clarity and new information might be gained by applying more precise methods in planning experiments and in evaluating experimental results. Some authors do not include enough experimental data to enable others to repeat experiments described. Frequently contributions deal with questions of local importance. Other papers merely emphasize the inconsistencies of yields from fertilizer trials without attempts to explain why such occurred. Some problems, namely, the absorption of ions by the gynophore or developing fruit and the necessity of such for fructification, have received considerable attention in recent years. To some extent, agreement has been reached on the essentials of that problem. Many phases of physiology of the peanut plant have been omitted due to the absence of published data; other phases are discussed briefly since they are assumed to be similar to that of most plants as given in general references (41, 50, 56, 60).

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GENERAL CHARACTERISTICS

Foliage

The peanut is a low-growing, annual, herbaceous, leguminous plant with one upright central stem (63, 68, 88) and numerous lateral branches, the lower of which may branch several times. The varieties are fairly well separated into the bunch and runner types. Lateral branches of bunch peanuts are more or less upright, while those of the runner type tend to be more prostrate. The central stem is usually taller in the more erect varieties. The leaves are compound, pinnate, consisting of two pairs of nearly equal leaflets, on a slender petiole of moderate length. The leaflets show nyctitropic movement and tend to orient themselves so as to intercept the greatest amount of light. So far as the writers know, measurements of the total leaf area of peanuts have not been made; however, the area would appear to be relatively large and well suited to photosynthetic activity. The leaves are moderately pubescent, which should aid in the retention of dust and sprays. During the latter part of the growing season there is often a progressive defoliation of leaves from the base toward the stem tip. While such defoliation might be associated with disease or nutritional deficiencies, there is a natural tendency for loss of leaves accompanying plant maturity.

The rate of leaf and flower appearance as recorded by Mohammad, et al. (58), is shown in table 1.
Maximum increase of leaf and flower appearance occurred with the bunch peanuts (Japan and Spanish) during the interim of 56 to 97 days after planting and from 70 to 125 days after planting with the runner

Table 1.—Average Increase in Number of Leaves and Flowers per Plant During Different Periods of Growth.

Variety	*Organ*	*Average fortnightly increase in number of leaves and flowers per plant between 42 and 154 days after seeding*							
		42-55	*56-69*	*70-83*	*84-97*	*98-111*	*112-125*	*126-139*	*140-154*
Small Japan	Leaves	19	51	99	87	37	16	0	0
	Flowers	9	39	103	96	91	28	2	0
Small Spanish	Leaves	15	76	92	71	27	10	0	0
	Flowers	12	75	192	175	118	55	15	0
Burmese	Leaves	17	76	80	98	64	44	32	26
	Flowers	3	37	80	154	233	136	73	32

type (Burmese). The fresh weight of the green shoots at 140 days was about 96 percent of the whole plant. Others (10) have found a similar relationship.

Flower, Gynophore and Fruit

The fruiting parts of the peanut plant have been of special interest to a number of investigators (10, 37, 45, 63, 68, 74, 81, 88, 90, 91). Botanists have known for more than a hundred years that the flowers were of one kind and complete, and yet the idea still persists, according to the literature, that peanuts produce two kinds of flowers. Flowers are borne in the leaf axils and one or more may appear in the same axil. They appear first at approximately 50 days after seeding and then daily throughout the flowering period. The orange-yellow flowers are fully open in early morning and usually begin to wither and die by noon of the same day. Therefore, an accurate record of flower production may be obtained.

Shibuya (74) found the length of the flowering period to range from 69 to 93 days with the bunch type. That period was 74 days in one experiment with the runner peanut. Maximum flower production occurred 50 to 60 days after the first flowers appeared. The bunch peanut produced approximately 600 flowers; the runner, approximately 1,000. However, there was considerable variation between individual plants.

Some data of flower production by the Dixie Runner peanut at the Florida Station (10) are given in table 2. Plants produced an average of 644 flowers during a period of about 80 days when grown in sand culture with the complete nutrient solution applied to both rooting and fruiting zones (table 2). An unbalanced nutrient supply had a pronounced effect on flower production, and blossoming virtually ceased when the root treatment of the plants was changed from a complete nutrient solution to distilled water. The results shown in tables 1 and 2 and others obtained by Shibuya (74) indicate that the runner peanut has more flowers than the bunch and that the flowering period ranges from 2 to 3 months or longer.

The gynophore or peg is usually noticeable within 7 days after the flower is fertilized. It is formed by division and elongation of cells back of the ovaries. The organ is geotropic and by elongation it transfers the ovaries from an aerial to a hypogeal position. Elongation generally ceases after the gynophore has penetrated the soil to a depth of approximately 2 inches. Then rapid embryo development usually starts within 10 days, and the fruit is mature at about 60 days after the appearance of the flower.

Table 2.—Mean Flowers per Peanut Plant (Variety Dixie Runner) as Affected by Nutrient Treatment. Roots of Plants Grown in Complete Solutions to July 1 (80 Days) and Deficient Solutions to August 20 (50 Days).

Nutrient treatment		*Flower production per 10-day interval after deficient solutions applied—July 1 to August 20 (50 days)*					*Mean total flowers July 1-Aug. 20*	*Mean total flowers during period of growth*
Root Zone	*Fruit Zone*	*July 10*	*July 20*	*July 30*	*Aug. 9*	*Aug. 19*		
Complete	Complete	109	84	100	87	96	476	644
Complete	Dist. H_2O	114	92	104	94	185	589	758
Dist. H_2O	Complete	44	2	9	17	14	86	250
−K*	Complete	100	83	78	50	15	326	481
−P	Complete	81	81	91	47	24	324	475
−Mg	Complete	107	109	112	60	55	443	583
−Ca	Complete	115	78	46	2	0	241	392
−S	Complete	64	52	61	61	59	297	423
−Micro-nutrients	Complete	54	64	33	15	17	183	324
L.s.d. 5%							179	164
L.s.d. 1%							246	225

*The negative sign indicates the element was omitted from the nutrient solution.

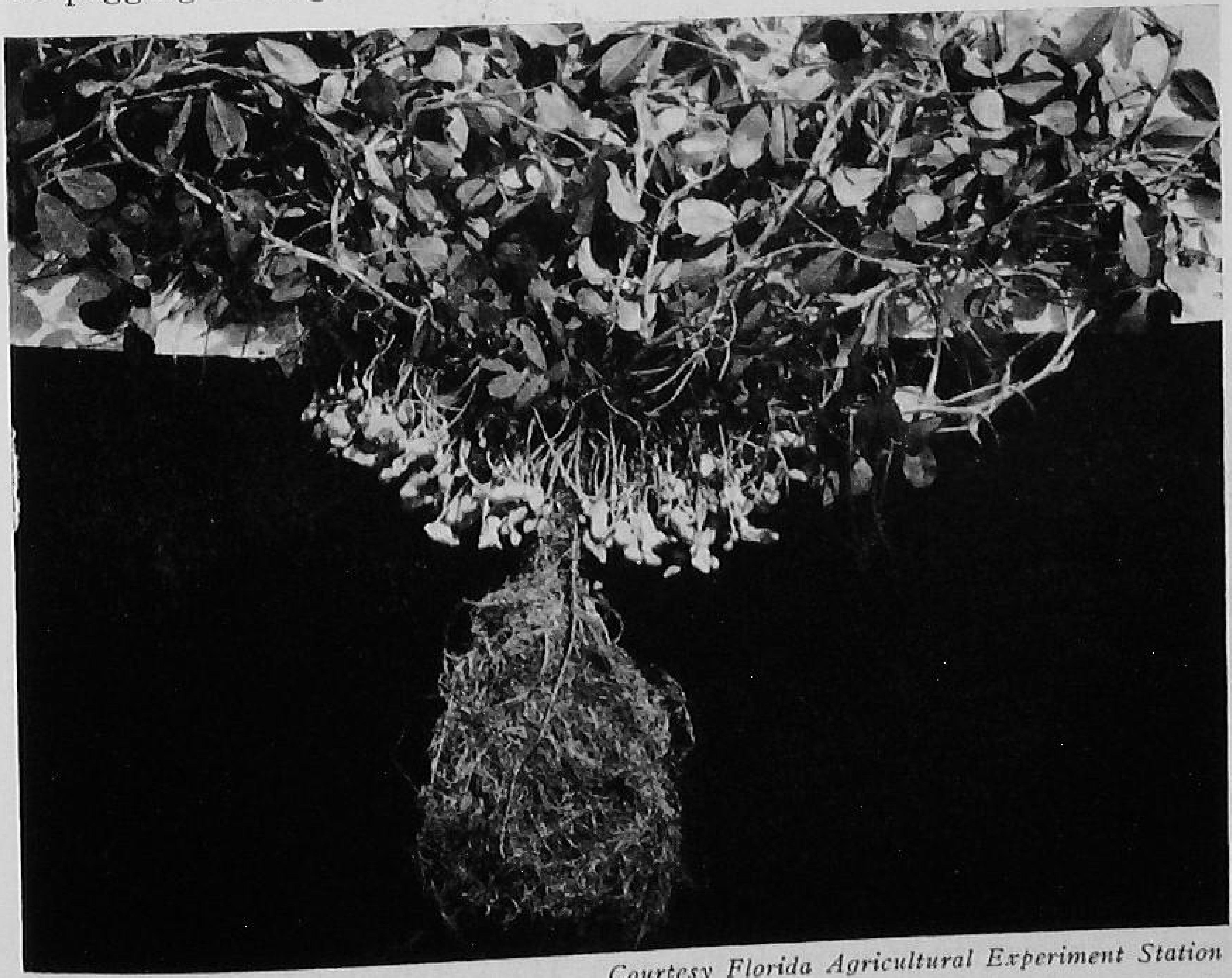
When the gynophore fails to contact the soil, its length rarely exceeds 6 inches, and then it eventually withers. The above-ground portion of the peg has a stem-like anatomy, while the underground portion has a root-like behavior and numerous epidermal outgrowths may be present (figure 1). The young fruit is fleshy in nature and the shell of the fruit sometimes has root-hair-like formations (81, 88, 90, 91). These characteristics of the fruiting organ suggest that it might absorb water and nutrients.

Courtesy Florida Agricultural Experiment Station

Figure 1.—Gynophore with root-hair-like outgrowths.

A high percentage of the flowers produce pegs. Shibuya reported that about 70 percent of the flowers of bunch peanuts and 75 percent of those of the runner peanuts produced pegs, while with the Dixie Runner variety 58.7 percent of the flowers produced pegs when plants were grown in sand culture (10).

Shibuya reported that 23 percent of the flowers of the bunch type and 9 percent of flowers of the runner type produced fruit (mature and immature) with an average of 45 fruits per plant for each type. Results at the Florida Experiment Station (10) show that 9.2 percent of total flowers resulted in fruit formation, while 24.4 percent of the pegs which entered the fruiting medium produced fruit when plants were grown in sand culture. In a similar experiment 17 percent of the gynophores of runner peanuts grown in a complete nutrient solution (37) produced fruit. Individual plants varied considerably, but the percentage of flowers effective in producing fruits was small. The nutrient supply of the plant (10, 37) influenced the effectiveness of the flowers and pegs in the production of fruits (figures 2, 3). Calcium, particularly when deficient in the pegging zone, gave a low percentage of fruit (figure 4).



Courtesy Florida Agricultural Experiment Station

Figure 2.—Dixie Runner peanut plant which received a complete nutrient solution in both the rooting and fruiting zone.

Courtesy Florida Agricultural Experiment Station

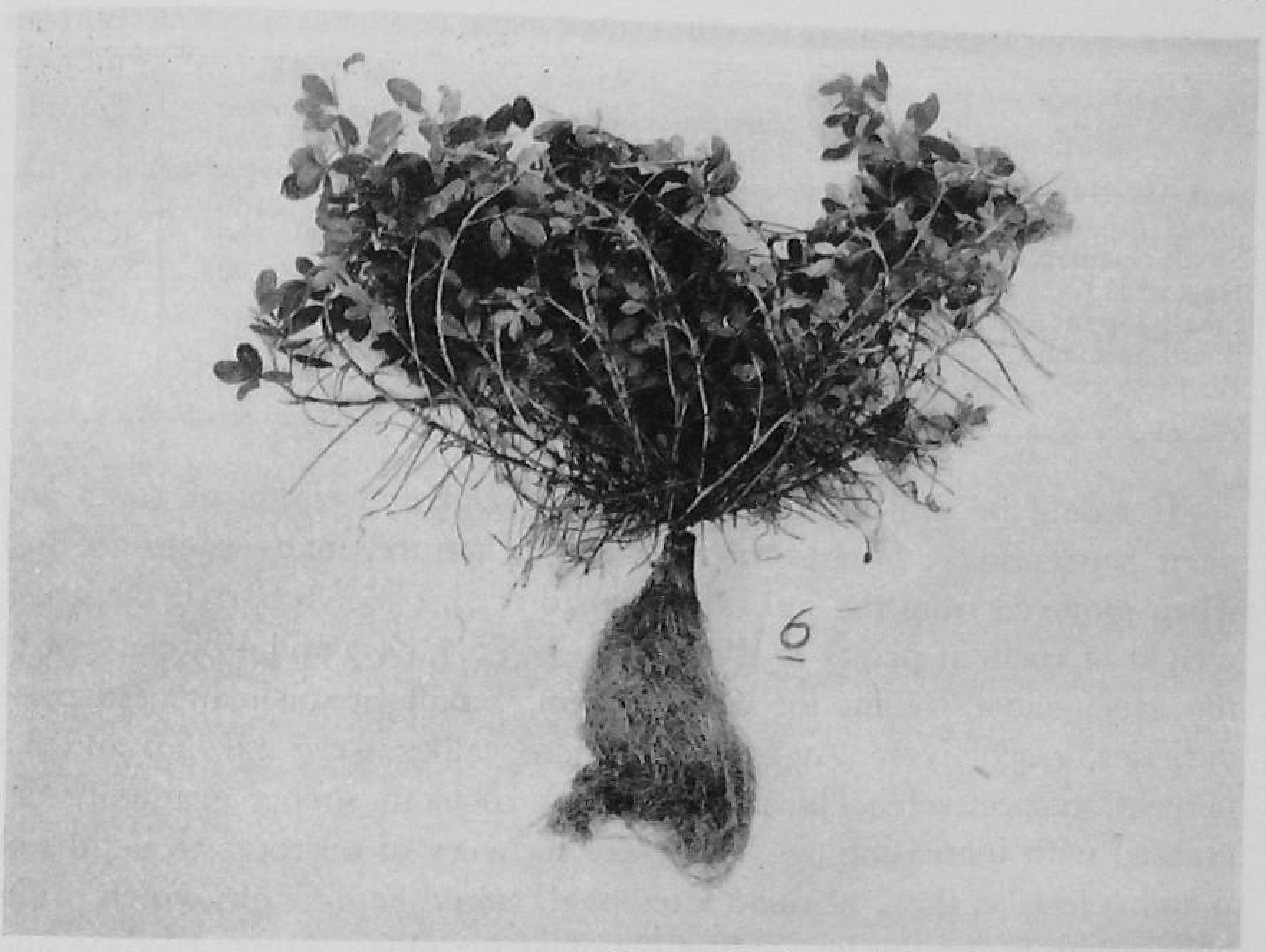
Figure 3.—Dixie Runner peanut plant which received a complete nutrient solution in the rooting zone and distilled water in the fruiting zone.

The peanut fruit may have one, two or more seed. It has been stated (4) that with fruit of those varieties which normally produce two seeds 7 percent of the ovules fail to be pollinated and that an additional 10 percent of the ovules abort during the early growth period, resulting in about 17 percent of the fruit being one-seeded.

The majority of mature fruit are located usually on the basal portion of the lowest branches, and results of Middleton and Harvey (55) indicate that there is a tendency for immature fruit and "pops" (fruits with aborted embryoes) to occur farther out on the branches.

Roots

The peanut plant has a well-developed tap-root system, similar to that of beans or peas, with numerous lateral branches extending a considerable distance in the soil. Several workers (17, 58, 63, 68, 88,) have made a careful study of the root system. The soft, fleshy, fragile roots collapse and dry quickly when removed from the soil. This tends to give the impression that the root system of the peanut is relatively small.



Courtesy Florida Agricultural Experiment Station

Figure 4.—Dixie Runner peanut plant which received a complete nutrient solution in the rooting zone and a calcium-deficient solution in the fruiting zone (Plant not grown same season as the ones in Figures 2 and 3).

Bruner (17) studied root development of the peanut at different stages of development when the plants were grown in a sandy loam soil in Oklahoma. When the soil was removed carefully with little disturbance of roots it was observed that the tap root of mature plants had a length of about 3 feet and that 4 or more rows of lateral roots grew horizontally for several inches and then downward for a distance of 2 or more feet. In general, branch roots were perpendicular to the main roots. Numerous temporary roots, designated as absorbing rootlets, were present on all roots of the permanent system. Such rootlets either deteriorated with age or developed into permanent roots. All young branch roots were considered absorptive rootlets. During early stages of plant growth the absorbing rootlets developed prominently in the first foot of soil, but later the subsoil became progressively more and more filled with them.

In India (58) a similar experiment was conducted using Burmese, a runner type, and Small Japan and Small Spanish, bunch types, with results shown in table 3. These data indicate that the extensive root system of the peanut might penetrate the soil to a depth of 6 feet.

Table 3.—Root Development (Penetration in Soil and Spread) in Centimeters

Variety	*Age in days*	*Penetration*	*Spread*	*Age in days*	*Penetration*	*Spread*
Small Japan......	18	66	31	140	130	105
Small Spanish....	18	60	41	140	150	80
Burmese.........	18	42	47	140	190	113
Small Japan......	110	136	132			
Small Spanish....	110	150	87			
Burmese.........	110	192	112			

It would be difficult to arrive at the relative weights of roots and plant shoots since, because of their fragile nature, many roots are lost when removed from the soil. Mohammad et al. (58), reported the green weight of roots of plants 18 days old to be 75.4, 84.5 and 49.5 percent of the green-shoot weight for Small Japan, Small Spanish and Burmese varieties, respectively. At 140 days these values were 3.8, 2.6 and 3.3 percent, respectively. The proportion of roots to shoots gradually decreased with increasing age. Complete recovery of all roots to depths of 5 and 6 feet, as these workers attempted, would be difficult, which probably accounts for the low values obtained for older plants. Bledsoe and Harris (10) found that when peanuts were grown in sand culture for 130 days, the average green weight of the roots of plants was 13.4 percent of the green weight of the tops. The collective information indicates that the root system of the peanut is much more extensive than is generally realized.

Adventitious roots sometimes develop on lateral branches of runner-type peanuts when in contact with the soil during humid conditions (37, 58). This has been given little attention but it is probable that such roots occur only on the more recumbent types under favorable moisture and weather conditions. However, at times, these roots might be effective in absorbing nutrients, and, if so, would increase the area of the absorptive system of the peanut.

Root Hairs

The majority of papers reviewed state that few if any root hairs occur on the root of the peanut plant. Pettit (63) failed to find root hairs while Waldron (88) found hairs in limited numbers as rosettes at the base of lateral branches and at tips of vigorously growing roots of young plants. Plants in larger containers with less air drainage did not produce tip hairs. Reed (68) observed few rosettes of hairs and no root-tip hairs on field-grown plants. Mohammad et al. (58), found root hairs on peanuts

grown in containers, but not when grown under field conditions. Failure to find hairs on the latter was thought to result from washing them off in the excavation process. It has been reported (3) that the epidermis of the roots of peanuts in the seedling stage sloughs off and typical root hairs are not produced, although peculiar tufts of hairs form at the base of most of the branch roots. Conversely, Bruner (17) indicated that root hairs were plentiful on the absorbing rootlets of the field plants he studied. Since the roots of peanuts are fragile, it is possible that the root hairs in many cases may have been lost in the harvesting process. If, however, peanuts have very few root hairs, as many believe, the major portion of root absorption would be through channels other than root hairs.

In summary, the plant has an extensive root system, the branches sometimes have adventitious roots, the gynophores produce root-hair-like outgrowths, and the fruit develops in the soil and sometimes has formations similar to root hairs on the shell. Nutrients could be absorbed by each of these organs.

WATER AND OXYGEN RELATION

The peanut is classified as a mesophytic plant but has xerophytic tendencies since it grows well in areas of Texas (68) and other States which may be considered as a transition zone between the mesophytic east and the xerophytic western plains.

Peanuts are usually grown on well-drained soils which are frequently sandy in nature. This ecological relationship suggests that liberal amounts of oxygen might be beneficial and that excessive moisture is not desirable for best development of peanuts. Shibuya (74) indicated that oxygen in the pegging area is necessary for fruit production, but the amount required was not determined. However, data relative to drought resistance, water and oxygen requirements of the peanut plant are not available so far as the writers are aware.

It is usually assumed that water enters plants largely through the root hairs. If peanuts have few root hairs, then water absorption would have to be by other means. As stated previously, adventitious roots, root-like hairs on pegs and sometimes on shells of fruit, may be present, but the relationship of those structures to water absorption has not been established. However, it has been shown that pegs and developing fruit do absorb some mineral elements (9, 19, 84). It is assumed that water movement through the peanut plant would be similar to that of most other plants.

LIGHT AND TEMPERATURE RELATIONS

Peanuts do not appear to be especially sensitive to length of day. The plant seems to grow very well from the tropics to the middle temperate zone. The day length in most of that area could be classified as intermediate, which suggests that such is satisfactory for peanut growth. In the United States peanuts are usually planted in April or May and maximum fruit development probably occurs during July and August when the days have begun to shorten. There is little seasonal variation in day length in southern India, and peanuts are sometimes planted in the fall in which case maximum fruit development occurs in the spring when days are lengthening.

Moore (59) found that Spanish peanuts bloomed abundantly when illuminated continuously for several weeks. Cheliadinora (21, 22) found that longer days increased the green weight and flower production, although the latter was not consistent. However, the ratio of fertilized to unfertilized flowers was higher with the short-day plants. Shaded plants, especially those on the shorter photoperiods, had fewer undeveloped pods and gynophores, which was attributed to earlier flowering when a more favorable lime and nutrient supply was available to aid development of fruit which had set. These results indicate the length of day has an effect on the peanut; however, critical studies of the photoperiodic response are lacking.

Although the intensity of light would seem to be important, few data have been published in reference to its connection with peanuts. Moore (59) found that when shaded plants were grown with 3- or 4-hour periods of daylight, blooming was practically prevented because of induced carbohydrate starvation, while Cheliadinora (21) produced good yields under partial shade. Those results indicate that slight shading is not particularly harmful as is a pronounced shortage of light.

Peanuts grown in an air-conditioned greenhouse at California Institute of Technology[2] required a high day temperature for normal development. Cool temperatures resulted in chlorosis and poor development. Similar results have been observed at the Florida Station. These observations seem to be in agreement with the results of Cheliadinora (22) that the photoperiodic treatment is effective only when the temperature is favorable during the flowering period. An increase in temperature also increased the yield of fruit (22), which agrees with the general assumption that the peanut is a warm-weather crop.

[2] Personal correspondence, W. P. Jacobs, Princeton University.

PHOTOSYNTHESIS. CARBOHYDRATE AND NITROGEN METABOLISM

It is assumed that photosynthesis and the carbohydrate and nitrogen metabolism of the peanut are similar to that of other plants and a general discussion of these topics may be omitted. However, it seems desirable to mention the work of Moore (59) regarding the carbohydrate-nitrogen balance in the metabolism of the peanut because of its possible importance in relation to yields of field-grown plants. Moore produced plants with various carbon/nitrogen ratios by altering the light and nitrogen supply. High-nitrogen plants were succulent, dark blue-green in color, with slender stems. High-carbohydrate plants were firm in texture, light in color, with thick stems. Both types were weakly vegetative and non-fruitful. Plants with a carbon/nitrogen ratio intermediate of the extremes gave satisfactory yields. However, it was pointed out that the fruiting tendency of the peanut was less sensitive to a change in the carbon/nitrogen ratio than that of the tomato plant. Results given in other papers (10, 18, 37) suggest that the carbon/nitrogen ratio as affected by nutrient supply has considerable influence on flower and fruit production. It is possible that many of the conflicting results in peanut experimentation would be explainable if such interrelations were better understood.

GROWTH-PROMOTING SUBSTANCES

Hormones or growth-promoting substances have not been used extensively on peanuts. Shibuya (73) reported that β-indole acetic acid in lanolin, (proportion of 1 to 10), hastened germination when applied to the scratched testa of seed of freshly harvested peanuts. He also reported (75) that the number of flowers per plant was increased when sprouted seed were soaked ½ and 2 hours, and unsprouted seed soaked 24 hours in a water solution of 0.02 percent of that compound. A lanolin preparation of the hormone applied to sprouted seed hastened flowering and increased the number of flowers.

Naphthalene acetic acid and five commercial hormone preparations were used with field-grown Spanish peanuts at the Alabama Station (1). The former and possibly one or two of the latter compounds slightly increased nut production. However, there seemed to be little advantage in their use and in some cases nodulation was depressed. Best results occurred when the compounds were used in association with seed inoculation.

Liu and Lou[3] were unsuccessful in stimulating the ovule into seed development by means of a variety of substances, including auxins, vitamins and different plant extracts. Long immersion of the gynophore in 0.02 percent naphthalene acetic acid caused roots to develop just above the undeveloped ovary. These workers were able to initiate fruit development by grafting gynophore tips to detached cotyledons and culturing them until the food supply of the cotyledons was exhausted.

Jacobs[4] indicates that the auxin which diffuses out of excised tips of gynophores exhibits polarity of transport, that is, moves only from ovary end toward the proximal end of the gynophore.

DORMANCY AND GERMINATION

Hull and Stokes (44, 81) reported dormancy of the peanut seed to be hereditary in nature and that the rest period of some seed might be as long as 2 years. The rest period of seed of the Spanish and Valencia types ranges from 9 to 50 days, while that of some runner types might range from 110 to 210 days. Seed of the Spanish types will germinate in the field unless harvested promptly after maturation. The longer rest requirement of the runner type is desirable if peanuts are left in the field to be "hogged off" during the fall or winter months. However, difficulties in germination of the runner peanut are rarely encountered since the rest requirement is satisfied in the interval between fall harvesting and spring planting. Hull (44) reported that the time required for breaking the rest period of Florida Runner and Spanish seed was increased when stored at 3° C. and decreased when stored at 20° to 40° C. A regular practice was followed of storing seed at 30° C. for 30 days after harvest, when quick germination was desired. The data indicate that the rest requirement of the peanut seed decreased as storage temperature increased from 3° to 40° C. which is opposite of that required by seed of many crops.

Results by Beattie et al. (7) indicate that winter storage temperatures of 32°, 40° and 70° F. had no significant effect on germination of several varieties of seed tested. Unshelled, stored seed seemed to germinate somewhat better than those shelled. Additional experiments to determine the effect of age on germination were conducted with Valencia and Improved Spanish varieties. When held at a storage temperature of approximately 70° F. there was favorable germination of Valencia peanuts for 5 years and of Spanish for 3 years, after which there was a dis-

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[4] Personal correspondence, W. P. Jacobs.

tinct loss in germination. Pons et al. (65) stored peanuts at minus 18° C., 1° C. and 27° C. for 4 years. Those stored at 27° C. were not viable, while those stored at lower temperatures germinated perfectly. In view of these results it appears that the viability of peanut seed may be good for from 3 to 5 years, depending upon the variety and the temperature of storage.

The viability of seed is usually determined by a germination test. Recently Brewer (16) reported good agreement between the tetrazolium chloride chemical test and germinability by an ordinary method. If a chemical method for determining the viability of peanut seed could be perfected, it might be of considerable advantage to persons involved in germination studies.

ABSORPTION OF MINERAL ELEMENTS

Mineral elements considered essential for plant growth, with minor exceptions, are absorbed by the roots from the soil. It is generally assumed that plant roots absorb ions either from the soil solution or by a root-colloid exchange.

Cations such as calcium, magnesium, potassium, sodium and hydrogen are sorbed by the soil colloids. Through the phenomenon of base exchange the cations are liberated to the soil solution and thus become available for intake by the roots. For example, carbon dioxide resulting from root respiration or from the decomposition of organic matter can react with the soil water to form carbonic acid. The hydrogen ions from the carbonic acid may displace cations attached to the soil colloids. The cations released to the soil solution as the result of ionic exchange can then be absorbed by the plant. The base exchange reaction is reversible and the amount of cations present in the soil solution at any time will depend on several factors. Jenny and Overstreet (46) contend that by a root-colloid exchange mechanism there can be a direct exchange of ions between the root and the soil colloid. According to this theory, ions sorbed on colloids may be as readily available to plants as ions free in solution.

The plant absorbs anions from the soil solution. Anions, with the possible exception of the phosphate ion, are not retained in any appreciable quantities in well-drained soils and unless used by crops are usually leached out of the soil rather rapidly. The water-soluble phosphate compounds are thought to be precipitated in the soil as insoluble or relatively insoluble compounds which largely prevent their leaching. The supply of soil phosphorus available to the plant depends on a series of complex

reactions which are not entirely understood. Two other important elements, nitrogen and sulfur, often occur in the soil in the form of organic matter and are released to the soil solution as a result of decomposition.

The above discussion is only an indication of some of the factors involved in supplying nutrients to the absorbing areas of plant roots. The concentration of anions and cations of the soil solution is usually increased by the addition of fertilizers, cover crops, lime and farm manures, as well as by nitrogen fixation by organisms and the removal of sulfur and nitrogen from the atmosphere by rain water.

The absorption and accumulation of ions by plant roots is a complicated process involving internal factors such as transpiration, respiration, photosynthesis and other metabolic activities associated with growth. Aeration, moisture, temperature and other environmental conditions surrounding the roots are also known to influence absorption.

The absorption of ions by roots of the peanut plant is assumed to be no different from that by other plants. However, since the fruit of the peanut develops in the soil, its relation to ion absorption has been given considerable attention. Several investigators (63, 68, 74, 88) suggested the possibility of water and nutrient intake by the gynophore. Van der Volk (85) observed that a soil extract aided fruit development, while Burkhart and Collins (19) were the first to demonstrate that an element, lithium, was absorbed by the gynophore and distributed within the plant. The latter workers also reported fruit quality to be benefited by the presence of calcium in the fruiting medium. Brady et al. (13, 15) demonstrated that fruit filling was significantly increased when a single calcium salt was added to the fruiting medium, while Harris (37) found fruit development to be negligible when a calcium-deficient nutrient solution was applied to that medium. It was reported (37) that yields were increased when the sulfate ion was used in the fruiting medium, while Brady et al. (15) failed to get a favorable response from that ion. It has been shown also that nitrogen^{15*} (84), phosphorus^{32*}, and radioactive cobalt (37) are absorbed in small quantities by the developing fruit and translocated to other parts of the plant. Bledsoe et al. (9) found calcium^{45*} to be actively absorbed by the shells and seed of developing fruit with some movement to other parts of the plant when the labeled calcium was applied to the fruiting medium. Conversely, when calcium^{45*} was applied to the roots of the plant, a small quantity of the labeled calcium was found in the shell, but never more than a trace could be detected in the seed of developing fruit.

* Small number refers to atomic weight.

FUNCTION OF NUTRIENTS AND DEFICIENCY SYMPTOMS

The nutrients as a group are thought to have a number of general roles, but in most cases it is difficult to state the exact function of a given element. A deficiency of any essential element adversely affects plant growth and yields. Mineral-deficiency symptoms are rarely found with the peanut when grown under field conditions but have been observed with plants grown in nutrient solution. Burkhart and Collins (19) described deficiency symptoms of the Virginia Bunch peanut in the young stage, while other workers (10, 37) have described the effects of a deficiency of the major elements for the Dixie Runner peanut at a later stage of growth. However, the symptoms described are, at best, roughly qualitative and in many instances are not specific. The role of nutrients in peanuts is assumed to be similar to that of other plants and is discussed briefly in connection with observed nutrient-deficiency symptoms.

Nitrogen. This element is the main constituent of protoplasm and occurs in a number of other organic compounds, one of the most important being chlorophyll. One of the main functions of nitrogen is obviously its requirement for the formation of new protoplasm in growth. Large amounts of nitrogen usually cause peanut plants to become dark green in color, grow rapidly, producing succulent vegetation that does not flower and fruit well (58). A lack of nitrogen in the peanut plant results in stunted growth, yellow foliage, reddish coloration of stems, and few nodules are found on the roots (19).

Phosphorus. Young meristematic tissue contains considerable phosphorus where it is utilized in the growing region in the formation of nucleoproteins and a number of other phosphorus compounds, including important respiratory enzymes and intermediates. Without phosphorus nuclear division and meristematic activity is decreased. Considerable quantities are stored in fruit and seed, hence the yield and size of seed may be affected. This element hastens maturity and root development. Peanuts with a low phosphorus content have a small leaf surface. The leaves are a dull bluish green in color, and in later stages they become yellowish and drop.

Potassium. Potassium occurs largely in the plant as soluble organic and inorganic salts. It is transported from the older parts to the actively growing regions of the plant under conditions of potassium deficiency. The exact function of potassium is obscure, but it is thought to play a part in the formation and translocation of various carbohydrates, the utili-

zation of nitrogen, and in cell division. Potassium-deficient peanut plants (10, 37) have few necrotic "scorch" areas at the leaf margins. In the late stages of potasium deficiency the stems near the tips of branches become reddish in color, then brown, which is followed by death of the tissue.

Calcium. Most of the calcium of plants occurs in the foliage and very little is found in the seed. The peanut seed is especially low in this element. Calcium-oxalate crystals are sometimes found in plant tissue. Calcium is considered relatively immobile in plants. Root growth of the peanut is severely affected by a shortage of calcium. A deficiency causes stunting and small distorted leaves near the tips of the branches. Interveinal brown pitted areas which coalesce to form larger necrotic spots develop on the affected leaves which give the leaves a bronze color. Basal stem cracks and die-back of the affected shoots occur during later stages. A deficiency of calcium (27) also affects the fill and quality of peanut fruit.

Magnesium. The chlorophyll molecule contains magnesium, and since a deficiency of this element results in chlorosis, it plays a part in photosynthesis. Although only a small proportion of the magnesium of the leaf can be accounted for by that in the chlorophyll, a large proportion of this element is carried in the green foliage, and there is a considerable amount in the seed. Magnesium leaf deficiency symptoms of the peanut (19) appear first as a chlorosis of margins of older leaves. In later stages the leaf margins may become orange in color. Magnesium has been demonstrated to be a factor in fruit production (10, 77, 78).

Sulfur. Sulfur is well distributed in the plant in the form of proteins, volatile compounds, and sulphates. Sulfur is not a part of the chlorophyll molecule. However, it may be required in the process of chlorophyll formation, since deficient plants have a pale green color. It seems to affect root development and to have an important part in respiration processes and cell division. The writers grew peanuts on a minus sulfur nutrient solution and the plants were smaller, but no other visible deficiency symptoms appeared. Burkhart and Collins (19) indicate that a deficiency of sulfur caused the leaves to be a lighter green color.

Iron. Plants grown on soils of high pH values frequently show iron-deficiency symptoms because of its unavailability. Iron is not a part of the chlorophyll molecule, and yet a deficiency results in chlorosis. It is assumed to have a catalytic effect in oxidation-reduction processes within cells, and it is found in enzymes. The quantity of iron present in plants is very small and it is quite immobile. Typical iron chlorosis developed when peanuts were grown in Hoagland's and Arnon's nutrient solution

Courtesy Florida Agricultural Experiment Station

Figure 5.—Dixie Runner peanuts showing the effect of 10 pounds per acre of copper chloride applied to Arredonda loamy fine sand before seeding. Right, complete fertilizer, including microelements; left, complete fertilizer, only copper omitted.

Courtesy Florida Agricultural Experiment Station

Figure 6.—Foliage of G. F. A. Spanish peanuts grown on soil treated before seeding with a complete fertilizer and all microelements, except copper. Note the extreme copper deficiency symptoms. The few yellowish-white spots are associated with the deficiency, but the relationship of the dark leaf spots has not been investigated.

(42) by the drip-culture method (76). The deficiency was corrected quickly by spraying iron on the plants.

Boron. A deficiency of boron affects the growing tissues, similar to that of calcium, resulting in death or growth abnormalities. The mobility of calcium is related to the boron supply. A boron deficiency for peanuts (19) resembles a calcium deficiency except that the necrotic areas are localized near the leaf margins.

Manganese. Manganese is in some way related to chlorophyll production since a deficiency results in a chlorosis of plants. It seems to play a part in oxidation and reduction processes possibly through its effect on enzymes. Shear and Batten (71) reported that when peanuts were grown on heavily limed soils the foliage was chlorotic and yields were reduced due to the unavailability of the manganese.

Copper and Zinc. A deficiency of copper results in chlorosis, prevents nitrogen from functioning normally (32, 35), and reduces yields. Harris reported that in copper deficiency the bud area of the peanut was affected, the terminal leaflets were chlorotic, small and distorted, a few yellowish-white spots appeared on many leaves, and the yields were greatly reduced (figures 5, 6). The pattern was much the same as that reported by Allison et al. (2) when peanuts were grown on soils in the Everglades and was similar to that attributed to thrip injury by Shear and Miller (72) and to leafhopper injury by Metcalf (53). It is quite possible that such characteristics are similar to those resulting from insect injury. However, the symptoms described above did not occur when copper was applied to the soil before peanuts were planted.

Zinc-deficiency symptoms of the peanut have not been described, although some workers (2, 6) have reported that applications of zinc have increased yields.

Molybdenum. Molybdenum is considered an essential element for some plants (82, 86). The foliage of the peanut plant had a dark green color when a small amount of molybdenum was applied to the soil, and shoot growth was increased by its addition to nutrient solutions (37).

CHEMICAL COMPOSITION

The data of mineral analyses of various parts of peanut plants as compiled from several sources (26, 33, 43, 48, 83) are given in tables 4 and 5. Few values for sulfur were found, and it would appear that the evaluation of this element would merit more attention. The results given in these tables merely indicate the mineral content of plants when grown under various conditions. Therefore, caution should be used in drawing

Table 4.—Mineral Composition of Various Parts of the Peanut Plant as Compiled from Sources Indicated. (Percentage Composition-Oven Dry Basis)

Variety	*Soil type*	*Fertilizer*	*Reference*	*Sampled days after seeded*	*Part of Plant*	*Nitrogen*	*Phosphorus*	*Potassium*	*Calcium*	*Magnesium*	*Sulfur*
Va. Jumbo*	Several	Not given	(83)		Kernels of Group H	5.15	.37	1.50	.11	.20	
Fla. Runner	Norfolk fine sandy loam	300 lbs/A 2-10-4	(48)	132	Kernels	5.11	.43	.67	.04	.15	
N. C. Runner (Probably)	Several	No treatment	(26)		"	4.37	.42	.72	.06	.19	.15
Va. Jumbo*	Several	Not given	(83)		Shells of Group H	1.69	.08	1.20	.34	.15	
Fla. Runner	Norfolk fine sandy loam	300 lbs/A 2-10-4	(48)	132	Shells	1.48	.10	.52	.17	.10	
N. C. Runner (Probably)**	Several	No treatment	(26)		Shells	.64	.05	1.01	.26	.10	
Fla. Runner	Norfolk fine sandy loam	300 lbs/A 2-10-4	(48)	22	Roots	3.30	.20	1.07	.75	.42	
" "	" "	" "	(48)	56	"	2.15	.27	.73	.78	.34	
" "	" "	" "	(48)	84	"	2.03	.29	.63	.74	.38	
" "	" "	" "	(48)	132	"	1.82	.22	.47	.67	.23	
Fla. Runner	Norfolk fine sandy loam	300 lbs/A 2-10-4	(48)	22	Foliage	3.84	.25	1.57	1.80	.35	
" "	" "	" "	(48)	56	"	3.46	.32	1.12	1.92	.57	
" "	" "	" "	(48)	84	"	2.48	.27	.75	1.59	.41	
" "	" "	" "	(48)	132	"	1.81	.25	.49	1.23	.28	
Va. Jumbo*	Several	Not given	(83)	July 5	Foliage of Group H	4.17	.35	1.07	2.18	.49	.39
" "	"	" "	(83)	Sept. 4	" " " "	2.93	.21	1.89	1.94	.54	.39
" "	"	" "	(83)	Oct. 11	" " " "	2.14	.10	2.21	1.89	.52	.35

*Drying method not reported
**Air-dry basis

conclusions about the differences in mineral composition, because there are practically no comparative analyses of different types of plants when grown under controlled or known conditions.

Seed

The mineral composition of mature seed of peanuts is relatively constant for a given variety. The nitrogen (protein) content of seed of the Spanish type is reported (79) to be higher than that of the Virginia peanut. However, while the data (5, 30, 33, 43, 91) of nitrogen content as well as that of other elements indicate varietal differences, it is not known whether such differences are significant. Data of mineral composition of seed as compiled from several sources (26, 33, 43, 48, 83) are given in tables 4 and 5.

Table 5.—Range in Percentage of Inorganic Constituents in the Peanut Kernel, After Hoffpauir et al. (33, 43)

Potassium	.68–.89	Zinc	.0017–.08
Calcium	.02–.08	Manganese	.0008–.05
Magnesium	.09–.34	Iron	.0018–.10
Phosphorus	.25–.66	Copper	.0007–.03
Sulfur	.19–.24	Boron	.0026–.05
		Molybdenum	.0008–.003

Hoffpauir and Guthrie (43) report that 87 percent of the nitrogen of the peanut seed is present as arachin and conarachin. Their data indicate that the amino acids usually considered essential for animal growth are present in the seed.

The average percent oil content of seed of control treatments from results of Middleton et al. (54) are as follows: 48.5, 49.1, 50.1 and 51.8 for Virginia Bunch, North Carolina Bunch, Spanish 2B, and White Spanish, respectively. Others (30, 43, 91) have reported results indicating some varietal differences in oil content. Several workers (30, 54, 62, 74) have shown that the oil content of mature seed is much higher than that of shrivels and immature seed. Those data suggest that an accurate description of seed samples should be included when oil analyses are reported.

The composition of oil from Spanish seed (33, 43) is given in table 6.

Peanut oil is nondrying, edible, and has a specific gravity of 0.917-0.920, refractive index of 1.467-1.470, saponification number of 186-194, and iodine number of 85-100 (33, 43, 93).

There is little change in the free fatty acid content or iodine number

Table 6.—Oil from Spanish Peanuts

Glycerides	*Percent*
Oleic	52.9
Linoleic	24.7
Palmitic	8.2
Stearic	6.2
Arachidic	4.0
Lignoceric	3.1
Unsaponifiable material	0.2
Total	99.3

of the oil of unshelled peanuts when stored in closed cans at 1° C. for 2 years (80). Oil of seed stored at 27° C. for 4 years (65) is much less stable than that of seed stored at 1° C. or at minus 18° C. for the same period. The oil of immature seed (62) has a higher free fatty acid content than that of mature seed.

Peanut seed is an excellent source of the B vitamins (33, 40, 43, 64) but contains only small quantities of the A, C and D vitamins. The approximate range in values of vitamin content as microgram of vitamin per gram of seed is as follows: riboflavin 1.05-1.57, thiamin 8.5-14, nicotinic acid 88-200, niacin 144-158, pantothenic acid 25, pyridoxin 3, biotin 0.34, inositol 1800, and folic acid 2.8. A considerable quantity of vitamin E is also present. Heat above about 150° C. decreases the vitamin content (29, 40). Fertilization of the soil is reported to have had no effect on the B_1 content of peanuts (67) but there were large varietal differences.

Values of some of the organic constitutents of the peanut seed as compiled from the results of Fraps (30) are given in table 7. Similar values have been published by others (40, 43). Results by Burkhart (18), Jodidi (47) and Moore (59) show that the organic composition of peanut seed can be influenced by environmental factors which affect the growing plant, but the data are too limited for generalization. The literature offers little information on the organic composition of the seed dur-

Table 7.—Range in Percentage of Carbohydrates and Other Components of the Peanut Kernel

Moisture	*Protein*	*Ether extract*	*Crude fiber*	*N-Free extract*	*Ash*	*Reducing sugars*	*Disaccharide sugar*	*Starch*	*Pentosans*
7.42	35.25	54.15	4.26	21.20	3.05	0.28	5.21	3.18	2.72
4.00	24.10	40.85	2.06	6.02	1.82	0.06	2.31	0.94	2.20

ing its development. As stated previously, mature seed have a higher oil content than immature seed. Very immature seed are quite high in free fatty acids (62) which decrease to a low level at maturity. Gallup and Staten (31) report an increase of protein and oil and a decrease of crude fiber and nitrogen-free extract of seed with shells during the last 5-week period of development.

Analysis (43) of the skin or testa of seed shows it to be high in fiber and ash and to contain appreciable amounts of fat and nitrogenous materials.

Shells

The mineral composition of shells is given in table 4. The mineral content of seed is little affected by fertilization, whereas that of the shell (28, 51, 52) has been used as an index of the calcium supply available to the developing fruit. Indications are that at least four factors affect the mineral composition of shells, namely (a) development of seed, (b) nature of the soil colloids, (c) calcium and other nutrients supplied the peanut, and (d) the length of time the fruit remains in the soil. Empty or poorly filled shells (28) have a higher nitrogen, potassium and magnesium content than the shells with well-developed seed, while the calcium content of the shell is not consistently affected by seed development. The peanut fruit seems to be able to obtain more calcium (51, 52) from some types of soil colloids than from others with the same degree of calcium saturation. Moreover, the application of calcium to the soil where peanuts are grown increases the calcium content of the hulls (28). Results by Bledsoe and Harris (10) indicate that the shell of the fruit absorbs very small amounts of magnesium and phosphorus from the medium in which it develops but actively absorbs calcium (9) and possibly potassium. The writers have observed also that the potassium content of shells of peanuts which cling to the vines when harvested is much higher than that of shells of peanuts removed from the soil after harvest.

The approximate organic composition of peanut hulls as compiled from the results of Fraps (30) is given in table 8. Little work has been

Table 8.—Approximate Composition of Peanut Hulls, (percentage—dry basis)

Protein	7.31	Reducing Sugars	0.59
Ether extract	1.19	Disaccharide sugars	1.72
Crude fiber	65.73	Starch	0.74
N-free extract	21.22	Pentosans	17.82
Ash	4.53		

done on factors which influence the organic content of shells. However, Moore (59) reported that shells of peanuts grown on a high nitrogen solution had a slightly higher ether extract and nitrogen content than those grown on a very low nitrogen solution.

Gynophores

A deficiency of any of the macro-elements (10) gives a low content of the particular element in the young gynophores. Furthermore, a deficiency of calcium or magnesium seems to cause the potassium content to be higher, and conversely. Apparently the level of nitrogen (59) in the nutrient solution influences the amount of the various carbohydrates in this organ.

Roots

The data of Killinger et al. (48) do not indicate any consistent striking differences in the mineral composition of the roots of plants which had received various fertilizer and sulfur-dusting treatments. However, there seemed to be a gradual decrease in content of some elements of roots when harvested at different dates after planting (table 4). The results of Moore (59) indicate that a high nitrogen content in the nutrient solution decreases the starch, sugars and other carbohydrates of the roots.

Foliage

The mineral composition of the foliage of peanuts is quite variable as shown in table 4. Some of the variation is probably due to variety differences, but few comparisons have been made of varieties grown under the same conditions. Values of peanut hay reported by Collins and Morris (26) differ from the values for the more mature hay given in this table.

Data of table 4 indicate that the mineral composition of the foliage is affected by maturity. This is further substantiated by the results of Burkhart and Page (20) who sampled leaf blades 2, 3 and 5 months after planting and found that the average concentration of calcium, magnesium, phosphate and sulfate increased with maturity, while the potassium content decreased from the first to second sampling, but increased from the second to the third sampling. Other results (20, 61) show that different parts of the foliage vary in mineral composition. Calcium seemed to be highest in the middle and lower leaves, potassium and phosphate in young tissue, magnesium in the more mature tissue, and sulfates in the lower portions of the plant, especially the lower petioles and stems.

Results by Bledsoe and Harris (10) indicate that the nutrient supply

to the roots has a pronounced effect on the mineral composition of the foliage. A deficiency of any major nutrient element to the root zone resulted in low values of that element in the leaves. A deficiency of potassium gave high calcium and magnesium values of the leaves, and a deficiency of either calcium or magnesium seemed to increase the potash content of the leaves. Other workers (19, 70) have secured similar results. Data of foliage analyses frequently show wide variation which is to be expected since it is known that both climatic and soil conditions influence the mineral content of plant leaves.

Some data of organic constituents of peanut hay are given in table 9.

Table 9.—Average Percentage Composition of Mowed Peanut Hay, Compiled from Results of Fraps (30)

Protein	11.09	Nitrogen-free extract	42.11
Ether extract	5.09	Ash	9.77
Crude fiber	21.94	Water	10.00

According to Moore (59) when peanut plants were grown on a range of nitrogen levels from very high to very low, the foliage consistently increased in total sugars, starch and dextrians, while the percentage of soluble solids and total nitrogen decreased as the nitrogen supply to the roots decreased. Hemicelluloses did not seem to be related to the nitrogen level on which the plants were grown. He suggested that total nitrogen rather than any specific nitrogen fraction should be used in correlating nutritional studies of the peanut.

FOLIAR DIAGNOSIS

Diagnostic methods involving analytical or plant-tissue tests have received considerable attention in recent years. In general, analyses of the entire plant are not recommended since specific tissues are considered to be more reliable as an indication of the mineral condition of the plant. Leaves are frequently chosen because their nutrient content more nearly reflects the supply from the soil. Standardization of tissue tests for known conditions may be useful especially when values of elements below the limits regarded as necessary for plant growth are the ones of interest from the viewpoint of fertilization.

Analyses of the peanut seed are of little diagnostic value since its mineral composition is relatively constant. The mineral content of the shell is influenced by nutrient supply but analyses of that organ would serve only as a fertilizer guide for the coming year. It would appear that

analyses of leaves or stems might be best for diagnostic purposes, especially if corrective measures are to be practiced.

Studies of tissue tests with the peanut are limited, but they seem to merit more attention, especially evaluations for known or controlled conditions. Burkhart and Page (20, 61) found variations in mineral content of different parts of the foliage of the peanut and state that the following tissues were most indicative for specific tests: Calcium, lower blades; magnesium, lower petioles; potassium, top petioles; phosphorus, top blades; sulfur, lower stems. The lower leaf blades of the peanuts were thought to be the most suitable tissue for determining deficiencies or excesses of all mineral nutrients in the plant. Chemical tests of the lower blades gave results which correlated with response to fertilization of field-grown plants.

SHEDDING OF FRUIT

Since the peanut blooms during a period of 2 to 3 months, there are various stages of fruit development as the plant approaches maturity. Many crops of indeterminate growth habit are harvested two or three times during a season. This is impossible with the peanut plant, since it is removed from the soil in the process. If peanuts are harvested early, there will be a large number of immature fruit, and if late, the most mature fruit will be left in the soil by the harvesting process (11, 39, 57, 66). The amount of shedding or fruit loss is undoubtedly related to a number of factors such as the degree of ripeness, amount of disease, insect damage, and various cultural treatments. Different seed inoculations (1) have necessitated harvesting at different times, also applications of gypsum (19) have resulted in early defoliation, making early harvest necessary. Shedding was decreased by sulfur dusting (11, 39) and was also influenced by fertilizer and other treatments (39). The number of fruit shed may be very few, but occasionally, when harvested late or under unusual conditions, as much as 75 percent (39) of all peanuts produced may be left in the soil after harvesting. Therefore, it is quite important in evaluating experimental results to know whether the technique used in harvesting accounts for all the peanuts produced.

NUTRITIONAL BALANCE

A lack of balance in nutrient supply (34, 49, 87) frequently accentuates nutritional disturbances. Published results (10, 19, 37) show that a deficiency of any element to the peanut will quickly produce abnormal plants which deteriorate rapidly. These deficiencies markedly affect the

vegetative character, flower and fruit production, and the mineral composition of the plants. This balance relates not only to the nutrient supply in the root area, but also in the fruiting area. Plants are vegetative and produce few fruit when calcium is not applied to the fruiting area (10, 37). Thus, the nature of the entire plant may be altered by the lack of calcium in the fruit zone. This does not mean that fruit absorption of nutrients is as important as root absorption, but the special requirements of the fruiting organs cannot be disregarded in the evaluation of fertilizer requirements.

A number of workers (14, 15, 19, 20, 70) have emphasized the effect of the calcium-potassium relationship on fruit production. Others (83) have indicated that the potassium-magnesium ratio is important in this respect and that the relation of the calcium, potassium and magnesium supply was indicative of the relative yield of marketable nuts. The importance of a balanced ration for plants is obvious. However, it is impossible to strive for a balanced nutrient program for the peanut until factors responsible for yields are identified.

NUTRITION AS RELATED TO DISEASE

The relation of the nutritional status of the peanut plant to its disease susceptibility is probably more important than generally realized. The prevalence of leaf-spot infection was far greater on plants grown on a magnesium-deficient solution than of plants grown on a deficiency of other elements (12). Applications of gypsum have also been reported (19) to cause the foliage of peanut to be very susceptible to leaf spot, resulting in early defoliation.

Concealed damage of the peanut seed is any internal breakdown of the cotyledons which is not evident upon external examination. Wilson (92) indicates that one type of concealed damage appears to be physiological in nature, but its occurrence was unimportant in Alabama. Internal breakdown of the seed might be related to nutrition but experimental evidence of such is lacking.

Sulfur dust is commonly applied to the foliage of peanuts to control leaf spot and certain insects. The sulfur may also act as a nutrient in some instances, especially where the supply of sulfur in the soil is low (8, 38). Some results[5] suggest that when sulfur was applied to the soil the foliage of the peanut plant was less susceptible to the leaf-spot infection.

[5] Unpublished results, Florida Agricultural Experiment Station.

DISCUSSION

Physiological processes relative to vegetative growth and fruit production of the peanut plant are assumed to be similar to those of many other plants. If differences exist, they are perhaps quantitative rather than qualitative. A balance of many physiological factors is necessary for the production of a healthy plant with a vigorous vegetative growth, many flowers, and adequate organic and inorganic reserves to support heavy fruiting. Whether the physical condition of the soil has an influence on penetration by the gynophore and subsequent development of the fruit is unknown. It has been shown that some mineral elements are absorbed by the fruiting organs and the data indicate that small amounts of available calcium in the fruiting zone aid fruit development. However, most of the mineral intake of the plant is by the root system.

In most well-drained soils the penetration of roots is limited not by soil conditions but by factors inherent within the plant. The data suggest that the peanut plant has an extensive root system and the roots are more or less continuously growing through the soil and are constantly coming in contact with soil particles from which cations can be displaced and absorbed. There are no data comparing the mineral uptake by the peanut plant with that of other plants from the same medium. However, it appears that the root system of the peanut is very effective in extracting nutrients from sandy soils of low nutrient supply. Whether that effectiveness is related to the nature of absorbing roots or to the extensiveness of the root system of the plant or the combination of both factors is unknown.

Physiological processes related to the nutrient supply in general determine the yield of field grown peanuts. The peanut is rather sensitive to an unbalanced nutrient supply and undoubtedly the application of one or two elements to the soil in some instances has produced an unfavorable nutrient balance which may account for some of the conflicting results of fertilizer field trials (11, 26, 39, 89). The only pronounced yield responses reported with peanuts have been on restricted areas where the available soil supply of calcium (27, 54, 69, 70), magnesium (70, 77, 78), or microelements (2, 6, 36, 71) has been very low. All these facts indicate the need for additional data in order to deal more effectively with the complex problems of soil and plant interrelations arising in the field.

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CHAPTER V

SOIL PROPERTIES, FERTILIZATION AND MAINTENANCE OF SOIL FERTILITY

By

E. T. YORK, JR. AND W. E. COLWELL[1]

Properties of Soils on Which Peanuts Are Grown

GENERAL SOIL PROPERTIES

A soil well adapted to the production of peanuts has often been characterized as a well-drained, light-colored, loose, friable, sandy loam, well supplied with calcium and with a moderate amount of organic matter. While such a soil may be considered to be "ideal," peanuts may be grown on soils differing markedly in physical and chemical characteristics.

A number of factors other than the yielding capacity of a soil determines its suitability for the production of this crop. Peanuts are normally grown on light sandy soils not necessarily because these soils produce the highest yields; in fact, there are many indications that better yields may be obtained on some of the heavier-textured soils. The principal reason for growing peanuts on the lighter soils lies in the fact that the crop is more easily harvested and the soil does not adhere to the pods. Many of the heavier-textured clays and clay loams are more deeply colored and tend to stain the pods to such an extent as to lower the market value of the crop. These factors are of little consequence when the crop is harvested by grazing hogs; however, it would not be a de-

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sirable practice to harvest nuts by hogs on many of the heavier soils because of the likelihood of damage to the physical structure of the soil.

Extremely heavy, sticky clays which tend to cake or crust are not well suited to peanut production because of the difficulty of peg penetration at fruiting time.

Under favorable conditions it is difficult at times to secure good stands of peanuts, and in wet, poorly drained soils satisfactory stands are virtually an impossibility. Peanuts have a distinct taproot and, as with other deep-rooted plants, it is essential that they be grown on a well-aereated soil with good drainage.

Variations in the chemical properties of peanut soils are limited somewhat by the exacting demands for proper physical characteristics. Soils of desirable color, texture and drainage usually have a relatively low exchange capacity . . . in most cases between one and five milliequivalents per 100 grams of soil. These soils are generally low in organic matter and reserves of plant nutrients. While peanuts may appear to make fair yields on land too poor for most other crops, it should not be implied that this crop is best adapted to relatively infertile soils. The fact that peanuts are grown on soils of low native fertility merely emphasizes the need for an extremely careful program of fertilization and management in order to maintain a high level of production of peanuts and other crops grown in the rotation.

PROPERTIES OF SOILS IN VARIOUS PEANUT PRODUCING AREAS

(1) The United States: The majority of the peanuts produced in the southeastern United States are grown on Coastal Plain soils. Batten (29) considers the Norfolk fine sandy loam as the soil best suited to growing the large-seeded type peanut; and a large acreage of the peanut crop grown in North Carolina and Virginia is produced on soils of the Norfolk series. The Sassafras, Marlboro, Moyock and Craven are also considered to be good peanut soils, while the poorly drained Bladen and Portsmouth soils are not adapted to growing this crop (29).

Generally, the soils of the small-seeded Peanut Belt in Georgia, Alabama and Florida are more sandy and have a lower exchange capacity and organic-matter content than the peanut soils of the Virginia-Carolina area. The Alabama Agricultural Experiment Station reports (4) that high yields of peanuts have been obtained on all the major soil areas of that State. However, most of the crop grown for market is produced on the light, sandy, Coastal Plain soils of the southeastern part of the State.

Most of the well-drained soils in central and northern Florida are satisfactory for growing peanuts, according to Killinger et al. (65) at the Florida Experiment Station. These workers have observed that some of the waste-pond phosphate fields and areas surrounding phosphate mines and lime quarries are especially well adapted to the production of high yields of peanuts. The Norfolk, Arredondo, Newberry, Orangeburg, Ruston, Red Bay and Magnolia soil series are commonly used for growing peanuts in Florida, while the "flatwood soils" are considered poor for the production of this crop.

Parham (84) reports that most of the peanuts produced in Georgia are grown on Coastal Plain soils in the southern part of the State. In areas where the peanuts are produced for market, the crop is grown on some of the relatively heavy soils such as the Greenville, Magnolia and Orangeburg. Lighter soils such as the Norfolk, Tifton and Ruston are used primarily in areas where the peanuts are hogged off, according to Parham.

Downing, Aull, Goodman and Peterson (48) have classified the soils of South Carolina into four groups based on their suitability for growing peanuts. A description of these groups follows:

"Group A: Excellent soil types for peanuts. Generally well drained with sandy loam or similar textured surface layers and with friable sandy clay loam on sandy clay subsoils beginning 10 to 24 inches below the surface. The soil as a whole is at least 36 to 48 inches deep and may be more. The topography is favorable for tillage operations and erosion is not a major problem.

"Group B: Good soil types for peanuts. Soils in this group, though generally similar to those in Group A, differ in characteristics such as thickness or texture of the surface layer, internal drainage, gravelliness or stoniness, or slope. The surface layer of a good soil may have either a lighter or heavier texture and may be shallower or deeper than that of an excellent soil.

"Group C: Fair soil types for peanuts. Soils in this group usually have one or more unfavorable characteristics such as a fine textured, very coarse textured, or very deep open or sandy upper layer, a noticeable eroded condition, steep slope, or imperfect drainage.

"Group D: Poor soil types for peanuts. Soils in this group are poor for peanuts because of characteristics that limit production or prevent proper cultivation of the land. Included are very sandy, very clayey, hilly to mountainous, wet or swampy, and rocky soils. If these soils are used for peanuts, yields will be very low." These suitability groups might well apply to soils of other peanut-producing regions.

The peanuts produced in other States in the South and Southwest (41, 67, 103) are grown on soils similar in physical and chemical characteristics to those used in the major peanut-producing areas in the Southeast.

(2) Other parts of the World: Workers in Jamaica (24, 25), Hawaii (66), Mexico (70), Cuba (109), Columbia (22), the Philippines (51), Australia (63, 64, 90, 111), Senegal (26), South Africa (79, 92, 98), Indonesia (23) and Rhodesia (108) have reported that the soils best suited for peanut production in their respective countries were, in general, those having the characteristics of the "ideal" peanut soil described earlier in this chapter. Hence it is evident that there is universal agreement on what constitutes the most desirable soil for growing peanuts.

THE FERTILIZATION OF PEANUTS

Peanut-fertilization practices have changed little in the United States in the past several decades; significantly, perhaps, neither have the yields. This is in sharp contrast to most of the other crops grown in the same areas.

A review of the peanut fertility research conducted by the southeastern experiment stations reveals a multitude of inconsistent and apparently conflicting data. The anomalous behavior of the peanut is pointed out as follows in a report of a recent study by the Southern Research Institute (21):

> "Not only does the peanut fail to respond markedly to direct applications of commercial fertilizers, but such responses as are observed are not constant, varying widely from field to field even on the same soil type. This behavior is in marked contrast to that of other crops such as corn or cotton for which the yield increase to be obtained for a given application of fertilizer can be predicted with almost mathematical certainty."

Despite this unusual behavior, peanuts are not unlike other crops in their basic nutritional requirements. In fact, with the normal systems of management in which both hay and nuts are harvested, peanuts remove relatively large amounts of nutrients from a soil (table 1). Certainly there is little reason to suspect that the chemical and physical laws which govern the absorption and utilization of nutrients by peanuts are not the same as for other plants. What accounts, therefore, for the erratic behavior of the peanut in response to fertilizer amendments?

Until recently little attention has been given to the fact that peanut varieties exhibit marked differences in nutrient requirements. Yet, while

striking differences among varieties in their response to fertilization may be reconciled, the anomalous, inconsistent results often obtained in fertilizer experiments with a single variety have been more difficult to understand. As pointed out in Chapter III, peanuts are normally self-pollinated, and the plants within a given newly selected strain or variety are essentially homogeneous. Therefore, genetic variability should be at a minimum and observed differences within such a variety must necessarily be a result of environmental influences. Failure to evaluate fully the various environmental factors influencing the growth of peanuts has made it difficult to interpret much of the experimental data.

Table 1.—Nutrients Removed from the Soil by One Ton of Peanuts and Two Tons of Hay (Pounds per Acre). Collins and Morris (43).

Part of the Plant	*Yield per Acre Pounds*	*N Pounds*	*P_2O_5 Pounds*	*K_2O Pounds*	*CaO Pounds*	*MgO Pounds*
Hay	4,000	78.80	10.60	82.20	55.00	25.20
Kernels	1,280	56.30	12.90	10.90	1.10	4.00
Hulls	720	4.60	0.80	9.90	2.83	1.10
Total pounds of individual nutrients removed		139.70	24.30	103.00	58.90	30.30
Percent of total nutrients in hay........		56.40	43.60	79.80	93.40	83.20

As pointed out previously, peanuts are often grown on soils of low native fertility. In many cases these soils are already deficient or on the threshhold of being deficient in a number of essential elements. It is common knowledge that under conditions where two or more nutrient elements are limiting growth, little benefit is derived from one nutrient unless all of the deficient elements are supplied simultaneously. The fact that peanuts often fail to respond to certain fertilizers may be due in part to a state of multiple nutrient deficiency.

It is difficult to evaluate much of the peanut fertility data in the literature because of the lack of information concerning the soil on which the work was conducted. A rather complete characterization of the physical and chemical properties of the soil would undoubtedly facilitate a better understanding of the experimental work with peanuts. Furthermore, an interpretation of peanut-fertilization data must also take into account the previous cropping and fertilization history of the soil.

Failure to appreciate fully the unique growth and fruiting habits of the peanut has certainly led to some of the confusion regarding the ferti-

lization of this crop. Since nutrients may be absorbed by the developing pegs as well as by the roots (34, 40, 110), the problem of fertilizer placement becomes of greater importance with peanuts than with many other crops. Recent experiments (20, 38, 45) indicate that to obtain the most beneficial effect of some nutrients, they must be supplied to the zone of fruit formation rather than to the plant roots. On the other hand, there are indications that it is best to supply certain other nutrients to the rooting medium (20, 37, 40). Another problem associated with fertilizer placement results from the fact that stand injury may occur when certain fertilizer materials are placed too close to the seed at planting (20, 31). Obviously the effectiveness of fertilizer materials may, to a large extent, depend upon proper placement, and such materials may lower yields unless they are used correctly.

The yield of peanuts may be influenced greatly by the stage of maturity of the plant at harvesting. If the crop is harvested early, a large proportion of the nuts is immature. Yet, if harvesting is delayed too long, an excessive number of the nuts may be separated from the vines and remain in the soil. There is evidence in the literature that certain fertility treatments may hasten or delay the maturity of the plants (30, 89). Certainly, plants must be harvested at comparable stages of maturity if the effects of fertilizer amendments are to be measured accurately.

Recent work has indicated that fertilizer treatments may influence the number of nuts which are shed and remain in the soil at harvest (35, 58). Therefore, this differential effect of fertilizers upon shedding may influence the yield of peanuts as normally measured. Perhaps the effect of certain fertilizer materials upon shedding is related directly to their influence upon maturity.

It should be evident from the foregoing discussion that peanut fertilization practices are not as well defined as with many other crops, and many of the anomalies associated with peanut fertilization are yet to be explained. Without question, experimental work with peanuts presents problems and requires techniques which are quite specific to this crop. However, when due consideration is given to the peculiar fruiting habits of the peanut plant as well as to the many important, but often unrecognized, environmental factors which influence its behavior, the available information pertaining to the fertilization of peanuts begins to assume a much more orderly pattern.

No attempt will be made in this discussion to review all of the experimental work with peanut fertility. Such a review would undoubtedly tend to confuse rather than clarify the issue because of the difficulty in eval-

uating much of the data in the literature due to the lack of information regarding the conditions of the experiments. Instead, certain data will be presented which tend to illustrate specific principles regarding the fertilization of peanuts and the maintenance of the fertility of peanut soils. From these data, it should be possible to formulate some fairly definite ideas regarding the use of fertilizer materials with peanuts.

EXPERIMENTS WITH NITROGEN, PHOSPHORUS AND POTASSIUM

Nitrogen

Being a leguminous plant, peanuts might not be expected to respond to large applications of nitrogen, and some of the experimental data would tend to verify this supposition. However, there is also considerable evidence which would indicate that nitrogen is of value in peanut fertilizers.

Recently, Prevot (91) has emphasized the importance of nitrogen in the nutrition of peanuts. The data presented by this French worker indicate that relatively large quantities of nitrogen are translocated from the leaves to the developing fruit, suggesting the importance of maintaining the peanut plant at a high level of nitrogen metabolism prior to the fruiting period. However, no evidence is presented by Prevot to indicate that amendments of nitrogen would be necessary when the peanut plant was properly inoculated with nitrogen-fixing microorganisms.

Responses to nitrogen might be expected if peanuts have not been well inoculated. While it has been generally assumed that no inoculation is necessary if peanuts are grown on land used previously for this crop, little has been done to determine if the most satisfactory inoculum is commonly present in peanut soils. Symbiotic nitrogen fixation may be inhibited somewhat in acid soils (69); hence response to nitrogenous fertilizers might be more pronounced on such soils. Unfortunately, most nitrogen-fertilization data in the literature are not accompanied with information relative to soil pH and to the degree of inoculation of the peanuts grown in the experiments.

It has been suggested (30) that nitrogen may be beneficial on soils which are extremely low in organic matter. Certainly differences in nitrogen levels in soils would be expected to be reflected in the response of peanuts to additions of nitrogenous fertilizers.

Workers at the Georgia Experiment Station (9) have found that nitrogen applied to Spanish peanuts caused a marked reduction in the disease, Southern root rot (*Sclerotium rolfsii*), and it was observed that

the yields of peanuts closely followed the incidence of the disease. These data would suggest that in some cases the beneficial effect of nitrogen may be due to its secondary influence in reducing the severity of this disease.

The results of experiments conducted over a 10-year period at the Georgia Coastal Plain Experiment Station (13) show a small, progressive increase in peanut yields with each increment of nitrogen up to 32 pounds. The maximum response, however, was only 151 pounds of nuts. In another single-element experiment there was little effect on yields of withholding nitrogen from a complete fertilizer (12).

As the result of several years of experimentation, workers at the North Carolina Station (43, 47) have concluded that nitrogen fertilizers have little effect upon the yields of large-seeded peanuts.

Several experiments conducted in Mississippi and reported by West (112) show little beneficial effect of 16 or 32 pounds of nitrogen in a complete fertilizer. In some cases the addition of nitrogen tended to result in a lower yield of nuts. The results of other work reported by West show responses of 200 to 300 pounds of nuts from the application of 100 pounds of nitrate of soda as a side dressing.

McClelland (68) in Arkansas, has reported that the addition of 18 pounds of nitrogen to a White Spanish variety resulted in an increased yield of 1,188 pounds of nuts and 1.38 tons of hay.

Earlier work at the Alabama Experiment Station (49) indicated that nitrogen was of little value in peanut fertilizers. However, more recent experiments (1, 107) have revealed some marked responses from the addition of nitrogen to Spanish peanuts. The data in table 2, obtained by the Alabama workers, show that in 1943 the yield of nuts was more than doubled by the addition of 120 pounds of nitrogen as nitrate of soda to a

Table 2.—The Response of Spanish Peanuts to Additions of Nitrogen on a Norfolk Sandy Loam. Reported by Alabama Agricultural Experiment Station. (1)

Treatment[a]	Pounds per Acre					
	1943		1944		Average	
	Nuts	Hay	Nuts	Hay	Nuts	Hay
No nitrogen..................	787	2,279	1,508	4,503	1,148	3,391
120 pounds nitrogen (750 pounds nitrate of soda)....	1,909	3,395	2,298	6,008	2,104	4,702

[a]All plots received 1,000 pounds of superphosphate and 250 pounds of muriate of potash per acre.

Norfolk sandy loam. The 2-year averages show an increase in yield of 956 pounds of nuts due to the applied nitrogen. Furthermore, large increases in hay yields resulted from the added nitrogen. These data are sharply in contrast with those obtained in earlier experiments with smaller rates of nitrogen.

The results of experiments conducted at two other locations in Alabama in 1944 are shown in table 3. The yields of Spanish peanuts were increased with each successive increment of nitrogen up to 80 pounds. The seed yield of runner peanuts was not increased by applications of nitrogen greater than 20 pounds per acre. However, the vegetative growth of both runner and Spanish type peanuts was stimulated by the added nitrogen. The Alabama workers (107) report that the high levels of nitrogen did not affect the percentage of sound or mature kernel, rotten kernels, or pops of either Spanish or runner type.

Table 3.—THE INFLUENCE OF AMENDMENTS OF NITROGEN UPON THE YIELDS OF SPANISH AND RUNNER PEANUTS ON A NORFOLK SANDY LOAM. REPORTED BY ALABAMA AGRICULTURAL EXPERIMENT STATION. (1)

Treatment[b]	*Yield of runner*[a] *Peanuts*	*Yield of Spanish*[a] *Peanuts*
	Pounds per Acre	*Pounds per Acre*
None	1,429	1,044
20 pounds nitrogen[c]	1,617	1,202
40 pounds nitrogen	1,605	1,352
80 pounds nitrogen	1,544	1,626
120 pounds nitrogen	1,635	1,686

[a] Peanuts were inoculated.
[b] All plots received 1,000 pounds superphosphate and 250 pounds muriate of potash per acre.
[c] Nitrogen applied as nitrate of soda.

In view of some of these data which show highly profitable responses from the application of nitrogen to peanuts, it might be well to re-examine some of the earlier work with this element. In most of these experiments less than 32 pounds of nitrogen were used, and in many cases recommendations are based on studies in which only 6 to 8 pounds of N per acre were applied. The recent work at the Alabama Station suggests that these amounts of nitrogen are insufficient to realize a measurable increase in peanut yields.

In 1922, Batten (30) in experiments with large-seeded peanuts reported that large quantities of nitrogen used on fairly fertile soil generally stimulated the top growth, delayed the maturity, and resulted in peanuts of poor quality without materially increasing the yields. Other investiga-

tors (96) have indicated that nitrogen may stimulate vegetative growth; however, the increased growth is often of little benefit because of the corresponding reduction in the shelling percentage of nuts. From our present knowledge of peanut nutrition it appears possible that the poor quality of nuts might have been due in many cases to a deficiency of calcium. Certainly the need for calcium and other nutrients would increase as the vegetative growth was stimulated, and little beneficial effect from nitrogen could be expected if some other nutrient were limiting.

In view of the conflicting evidence in the literature, it is not possible to reach a satisfactory conclusion relative to the use of nitrogenous fertilizers with peanuts. However, there are sufficient data to suggest the possibility of obtaining profitable responses from nitrogen when adequate supplies of other nutrients are present. Surely this problem warrants further investigation.

Phosphorus

There is considerable disagreement in the literature regarding the value of phosphorus in peanut fertilizers. Harper (56) and Pate (85) have indicated that phosphorus stimulates the setting of fruit and decreases the number of unfilled pods. Other workers (89, 108) have suggested that phosphorus may hasten the maturity of peanuts. While there is no question regarding the plant's need for phosphorus, table 1 shows that a relatively small amount of this element is absorbed by the peanut plant and suggests that little may be gained from large applications of phosphatic fertilizers except, perhaps, on soils extremely low in available phosphorus.

Some of the earlier work in the United States and in several foreign countries indicates that a greater yield response might be obtained from phosphorus than from either nitrogen or potash. Batten (30) in 1922 reported that phosphorus gave better results than any other element in peanut fertilizers and recommended the use of 300 to 500 pounds per acre of superphosphate. On some of the Black Belt soils of Alabama, peanuts were found to be more responsive to phosphorus than to any other element (3). As the result of experiments conducted in Mississippi, Ferris (52) in 1922 concluded that "acid phosphate" gave the cheapest increase in the production of peanuts.

Kerle (62), in New South Wales, indicated that superphosphate had proven to be the most beneficial fertilizer for peanuts in that country. Moses and Sellschop (79), in South Africa, reported profitable increases in peanut yields from the use of 300 pounds of superphosphate. Krauss

(66) has indicated that applications of 250 to 500 pounds of phosphate to peanuts in Hawaii have been very beneficial.

In a recent experiment conducted by Massibot and Vidal (71) in Senegal, phosphate at the rate of 132 kilograms per hectare (approximately 125 pounds per acre) was found to increase markedly the yields of peanut hay and nuts. The large responses to phosphorus were obtained on a soil which had been fallow for 2 years. These workers also observed that peanut yields were increased as the result of the residual effect of phosphatic fertilizers applied the previous year to millet.

Numerous field experiments with peanuts conducted by the North Carolina Agricultural Experiment Station (46, 47) have failed to show any marked beneficial effect of phosphatic fertilizers when peanuts were grown in rotation with other crops which had received liberal applications of phosphatic fertilizers. However, when peanuts were grown continuously on the same soil, yields were increased by additions of phosphate on soils low in available phosphorus (16).

The results of a 10-year study at the Georgia Coastal Plain Experiment Station (13) in which peanuts were grown after crops which had been "fairly well" fertilized showed no effect of additions of 48 pounds of P_2O_5 on peanut yields. In experiments conducted at several locations by the Georgia Experiment Station (6) on soils which had been "well fertilized in past years," little response was observed from applications of phosphorus.

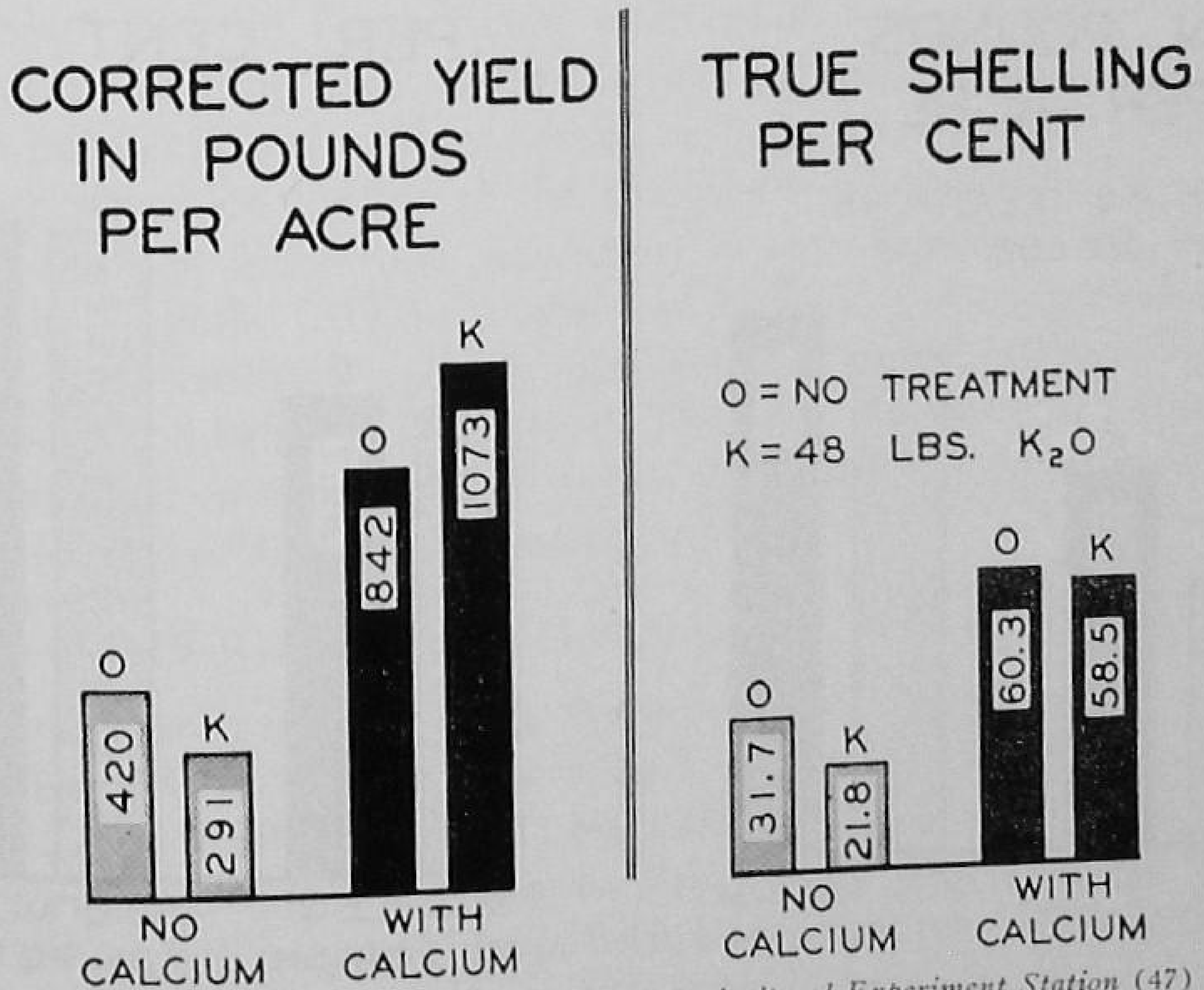
The behavior of peanuts toward amendments of phosphatic fertilizers appears to be dependent upon a number of factors. If the crop is grown on "new" land or land which has been fallow for a number of years, or in a rotation with other nonfertilized crops, phosphatic fertilizers would undoubtedly be beneficial in many instances. However, when grown in rotation with other well-fertilized crops, peanuts might be expected to give little response to phosphorus amendments.

In view of the rather exacting demands of some varieties of peanuts for calcium, some of the increases in yields which have been attributed to phosphorus may have been due to the calcium supplied in the phosphatic fertilizers. Evidence of this is found in the work of Albrecht (27) which shows that the addition of superphosphate to Spanish peanuts favorably influenced yields while triple superphosphate was of no value. O'Brien (82) has also found that superphosphate and dicalcium phosphate were superior to triple superphosphate as a source of phosphorus for peanuts. Ordinary superphosphate is approximately 50 percent by weight of calcium sulfate.

Potassium

It is well recognized that peanuts are especially heavy "feeders" of potassium. Yet, despite the relatively large amount of potassium absorbed by peanuts (see table 1) the yield responses to applications of potash fertilizers are often very small or negligible, even on soils of low K content. In fact, peanuts appear to be quite unique in their ability to absorb potassium and make satisfactory growth on soils so deficient in available potassium that many other crops would fail to grow.

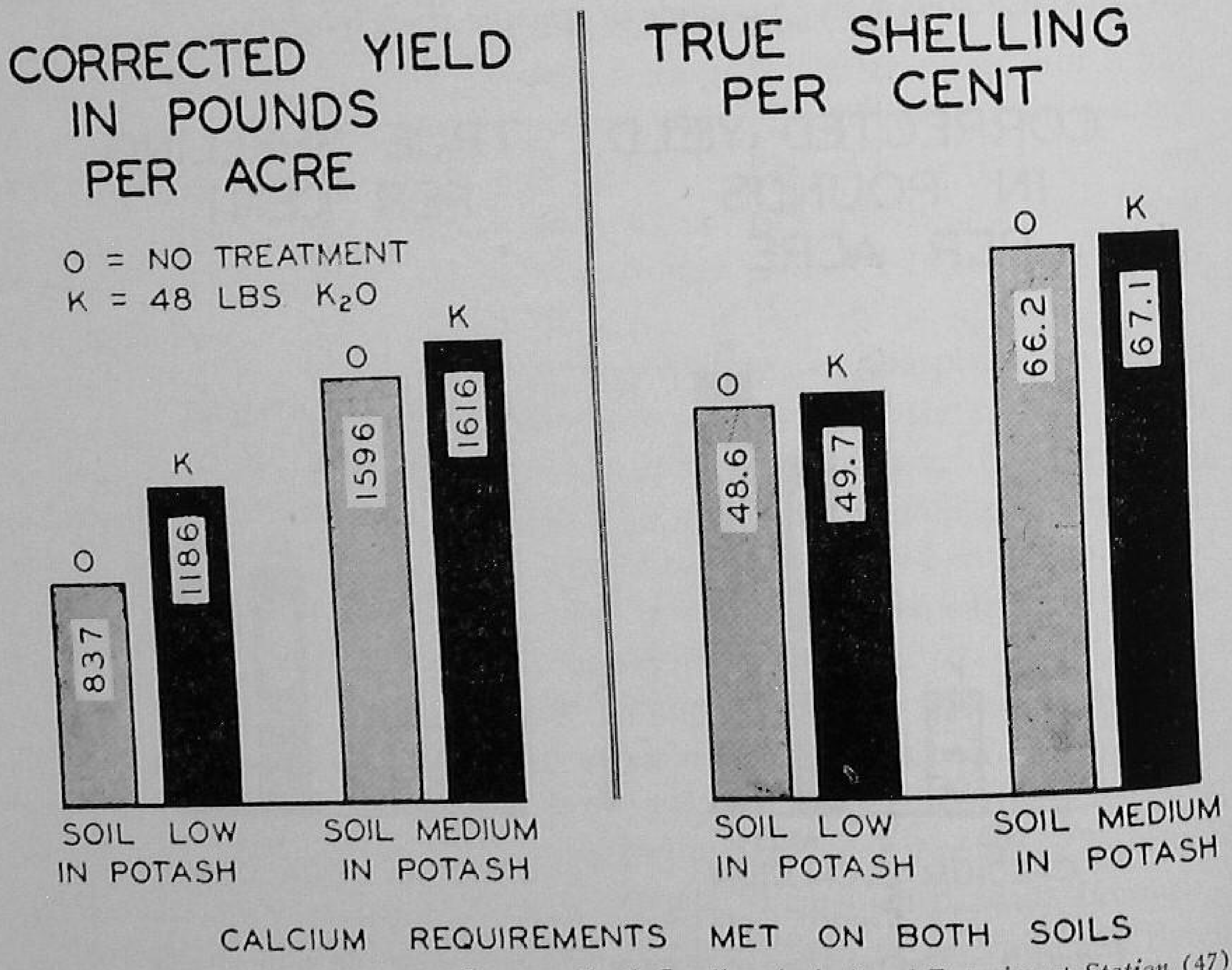
An average of the yields obtained in an experiment conducted at the Georgia Coastal Plain Experiment Station (13) over a 10-year period shows that the use of 32 pounds of potash in combination with nitrogen and phosphorus increased the yield of Spanish peanuts only 139 pounds per acre. In experiments conducted by the North Carolina Station (46) between 1938 and 1943, 12 to 48 pounds of K_2O per acre proved beneficial in only one of the locations. In several instances the yields were actually reduced by the application of potash. The exchangeable potassium level of these soils was 75 pounds or greater at each location.



Courtesy North Carolina Agricultural Experiment Station (47)

Figure 1.—The response of peanuts to potash, with and without additions of calcium. Soil = Kalmia sandy loam; pH = 5.3; exchange capacity = 3.13 m.e./100 grams; exchangeable Ca, Mg, and K = 0.50, 0.27 and 0.12 m.e./100 grams respectively. Calcium equivalent to 130 pounds CaO was applied as $CaSO_4.2H_2O$ on the foliage in July.

Other experiments conducted in North Carolina (18, 37, 47) in 1942, 1943 and 1944 revealed some interesting relations regarding the response of peanuts to potash. It was found that on a soil low in both potassium and calcium there was a significant increase in yield from the addition of potash when adequate calcium was supplied. Without the addition of calcium, potash was found to decrease the yields of peanuts, however. This relation is illustrated in figure 1. Apparently the deleterious effect of potash in the absence of applied calcium was due to the reduction in shelling percentage (figure 1). As shown in figure 2, the response of peanuts to potash was found to be dependent upon the initial level of potassium in the soil. On soils at a medium potassium level, fertilizers containing this element were of little value. It was observed that the vegetative growth was stimulated by the added potash and that the increased yields were due to the effect of the potash on the plant size and number of fruit rather than on kernel development. Other workers (40, 76, 96) have also observed that potash may stimulate vegetative growth



Courtesy North Carolina Agricultural Experiment Station (47)

Figure 2.—The response of peanuts to potash amendments on soils containing different amounts of exchangeable potash. Soil low in potash was a Norfolk sand with 0.04 m.e. exchangeable K; soil medium in potash was a Norfolk sandy loam containing 0.10 m.e. exchangeable K per 100 grams.

but cause a reduction in peanut quality. However, under the conditions reported in figure 1, this harmful effect of potash on peanut quality was overcome by maintaining an adequate level of calcium in the soil.

Other studies in Georgia (6, 7, 8, 13), Florida (5, 65, 105), Alabama (1, 49), Mississippi (14), South Carolina (83) and elsewhere (67) have given no consistent results with potash fertilizers, and it would be impossible to make a recommendation regarding the use of potash which would be applicable under all conditions. Generally the consensus among the southeastern experiment stations is that it is preferable to apply relatively large amounts of potash to the other crops grown in the rotation rather than to supply this material directly to peanuts. However, on soils extremely low in potassium or where heavily fertilized crops are not included in the rotation, it may be desirable to apply some potash directly to the peanuts.

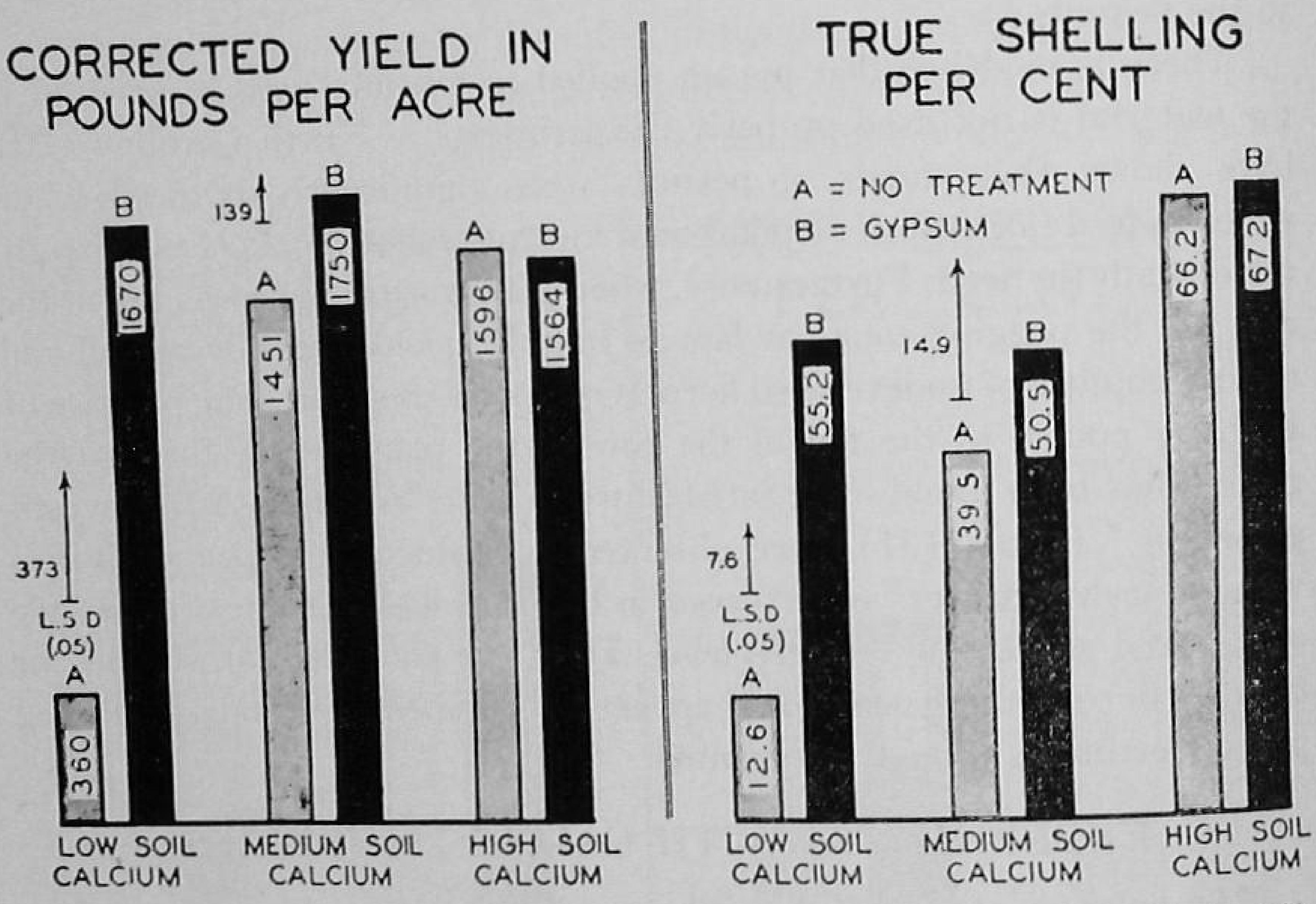
There is evidence that potash applied to peanuts may be harmful if the material is not used properly. Experiments in North Carolina (20) have shown that stands of peanuts were significantly reduced when either muriate of potash or potassium metaphosphate was placed directly underneath the seed. Furthermore, when potash was applied on top of the row (in the pegging zone) as late as June 15, yields were decreased and a large number of undeveloped kernels or "pops" resulted. The practice of applying potash to the top of the row as the plants come through the ground has been found to be satisfactory in some localities (20). Investigators in Virginia (31) have observed no reduction in peanut stands when potash fertilizers were placed in bands at least 2 inches to the side of the seed and below the seed level. Thus side placement at planting or top dressing at emergence would appear to be the best method of applying potash fertilizers directly to peanuts.

EXPERIMENTS WITH CALCIC MATERIALS

The calcium requirements of the peanut plant have long been recognized. Jones (61) in 1885, describing a soil suitable for the growing of peanuts, said, "Unless (the soil) contains a goodly percentage of lime in some form in an available state, no land will produce a paying crop of pods, although it may yield large luxuriant vines." In a subsequent discussion, Jones pointed out that a soil must contain adequate calcium in order to insure "solid pods." Thus, the need for and function of calcium in the production of peanuts was recognized some 65 years ago and perhaps earlier.

The Importance of Calcium in Peanut Nutrition

The significance of calcium in the nutrition of peanuts is clearly depicted in figure 3. The data in this graph were obtained in experiments conducted by the staff at the North Carolina Agricultural Experiment Station (47) on soils ranging in calcium levels from approximately 450 pounds to 2,200 pounds of calcium-carbonate equivalent per acre. Very marked increases in yields were obtained from additions of gypsum, a soluble calcium salt, to soils low in calcium. Yet it is evident that little might be gained from amendments of gypsum to soils already well supplied with calcium. Furthermore, it is obvious that increases in yields obtained from the gypsum on low calcium soils were due for a large part to the effect of the calcium on the shelling percentage.



Courtesy North Carolina Agricultural Experiment Station (47)

Figure 3.—The effect of gypsum upon the yields and shelling percentage of peanuts growns on soils of different calcium levels.

Chemical Characteristics	*Soil Low in Calcium*	*Soil Medium in Calcium*	*Soil High in Calcium*
pH	6.0	5.5	5.6
Exchange Capacity—m.e./100 gms.	2.66	3.24	4.02
Exchangeable Ca—m.e./100 gms.	0.45	1.39	2.21
Exchangeable K—m.e./100 gms.	0.05	0.08	0.10
Exchangeable Mg—m.e./100 gms.	0.18	0.29	0.38

Many other investigators (80, 109) have indicated that the quality of peanuts is influenced by calcium to a greater extent than is the quantity of fruit. A deficiency of calcium in soils is usually manifested by a large number of "pops" or unfilled pods. The better quality of nuts in soils well supplied with calcium is evidenced by a whiter, firmer hull, well-developed kernels and an increase in weight per bushel of unshelled nuts. Colwell and Brady (44) have observed that in addition to decreasing the number of pops, calcium also functions in increasing the number of two-cavity fruit formed by the large seeded varieties. They suggested that calcium exerts this favorable effect by preventing abortion of the fertilized ovules which apparently occurs at a very early stage of fruit development before shell enlargement has begun. Brady, Nelson and Reed (15) have further indicated that calcium may increase the percentage of pegs which make shells.

As early as 1911 Duggar and Funchess (50) reported highly profitable increases in peanut yields from the use of lime in Alabama. In recent tests on Alabama soils which were relatively low in calcium and which had been subjected to intensive cultivation, Rogers (95) obtained very marked responses from the use of lime. Increasing the calcium level of the soil from approximately 400 pounds per acre of $CaCO_3$, equivalent to 800 or 900 pounds by the application of lime, resulted in a five-fold increase in yield of Spanish peanuts. Rogers reported that on soils low in calcium, additions of lime up to 3,000 pounds gave marked increases in yield of both Spanish and runner-type peanuts.

The results of a 10-year experiment conducted on a Tifton sandy loam by the Georgia Coastal Plain Experiment Station (13) showed that lime applied at the rate of 500 and 1,000 pounds per acre was of little value for peanuts. It was reported that the test "followed a general rotation in which other crops were fairly well fertilized." However, there is no indication of the calcium level of the unlimed soil.

In field experiments conducted in Uganda, East Africa, peanuts have shown no response in yields to amendments of lime (60). Workers in Senegal have reported a 35-percent increase in peanut yields from applications of 3 tons of lime per acre (60).

In a test of some 13 different varieties and strains of peanuts by McClelland (68), in Arkansas, increases of as much as 2,000 pounds of nuts and 3 tons of hay per acre were obtained with certain varieties from the application of 1,056 pounds of crushed limestone. The average increase in yield from lime with all the varieties was 890 pounds of nuts and 1.03 tons of hay.

Numerous tests conducted in Virginia have emphasized the need for calcium in the production of large-seeded varieties of peanuts. Batten (29) has suggested that an adequate calcium level may be maintained by applying 1,500 to 1,800 pounds of ground limestone per acre or its equivalent to peanut soils every 3 or 4 years. Large applications at one time have been found to be harmful. It was suggested that the pH be maintained between 5.8 and 6.2, and on the lighter soils the pH should never exceed 6.4. Batten reports that gypsum is almost universally used where the large-seeded peanuts are grown. However, this material has not been found to increase yields where lime has been used to maintain a "suitable" soil reaction.

The results of other experiments at different localities in the United States are varied. The response or lack of response may be explained in most cases by the mineralogical nature of the soil and the level of calcium. Generally, however, the soils on which peanuts are grown are relatively low in calcium and unless large amounts of lime have been applied in recent years some benefit may be expected from the use of this element.

Sources of Calcium

There is considerable evidence that peanuts will make satisfactory growth on relatively acid soils provided the calcium needs of the plant are satisfied. Thus, the primary consideration in the use of lime or other calcium-bearing materials for peanuts is to furnish an adequate supply of the nutrient calcium. The three calcium-bearing materials most commonly used for peanuts are gypsum or landplaster ($CaSO_4.2H_2O$), calcitic limestone and dolomitic limestone. Numerous tests have been made to determine the most satisfactory of these materials for peanuts.

Little differences in peanut yields were observed at two locations in Mississippi (14) from the use of 400 pounds of gypsum under the seed, 400 pounds of gypsum dusted on the plants, and 400 pounds of dolomite. However, little response was obtained from any of these treatments. In other experiments 1,200 pounds of lime yielded somewhat better than 400 pounds of gypsum.

Comparable yields of large-seeded peanuts were obtained in experiments in Virginia (30) with 500 pounds of gypsum, 2,000 pounds of burnt shells, and 4,000 pounds of ground shells. Other studies (32) indicated that ground oyster shells and dolomitic limestone were of equal value for peanuts.

Rogers (95) studied the effect of ten sources of calcium upon the yield

of Spanish and runner peanuts grown in a rotation with vetch. The lime materials were applied broadcast at two rates, 1,500 and 3,000 pounds per acre, to a Norfolk sand. The results are shown in table 4. All of the calcium sources were found to be approximately equal in value except the calcium silicate slag which gave profitable increases over no lime but was inferior to other liming materials. Dolomitic limestone was found to be

Table 4.—PEANUT YIELDS AS AFFECTED BY KINDS AND RATES OF LIME AND GROWTH OF VETCH AS A GREEN MANURE CROP, AUBURN, ALABAMA.* (95)

Lime treatment		*Soil pH Sept. 1945*	*Yields of vetch turned under, pounds per acre 1942-45*	*Yields of Spanish peanuts, pounds per acre 1943-45*
Kind of lime	*Pounds per acre applied, 1941*			
None	—	5.3	5,766	1,093
Calcic limestone (Av. of 3 sources)	1,500	5.3	14,720	2,073
	3,000	5.5	16,701	2,307
Dolomitic limestone (Av. of 3 sources)	1,500	5.3	16,073	2,165
	3,000	5.6	18,615	2,633
Oyster shell	1,500	5.3	16,874	1,871
	3,000	5.6	16,894	2,242
Paper mill waste	1,500	5.3	18,743	2,203
	3,000	5.7	16,757	2,415
Blast furnace slag	1,500	5.2	13,243	1,666
	3,000	5.6	15,694	2,198
T.V.A. Ca-silicate slag	1,500	5.4	14,822	1,978
	3,000	5.6	15,341	1,732

*Maximum response to lime obtained in these tests in small plots by turning under vetch each year as a green manure crop, close spacing of plants, and fertilizing both vetch and peanut crop with 300 pounds per acre of 0-14-10. Peanuts were planted and dug each year from these plots on Norfolk loamy sand since 1942. (The 1942 crop was lost after harvesting.)

superior to calcitic lime on an intensively cropped Norfolk sand but was not significantly better in larger-scale field tests on sandy loam soils.

Experiments were conducted in North Carolina (47) to compare the relative values of dolomitic and calcitic limestone and gypsum, applied at different dates and in different manners. The results are shown in table 5. Calcitic limestone was found to be distinctly superior to dolomitic limestone, regardless of the time of application. Furthermore, almost twice as much dolomite had to be applied to furnish the same amount of

calcium as was supplied by calcitic lime. Pure magnesium carbonate was found to decrease the yields somewhat. At one location 640 pounds of gypsum appeared to be superior to calcitic lime while at another the lime resulted in higher yields.

It is obviously very difficult to evaluate the effectiveness of various sources of calcium. In many instances arbitrary comparisons have been

Table 5.—Yield of Virginia Bunch Peanuts as Affected by Different Calcium and Magnesium Carriers. Reported by North Carolina Agricultural Experiment Station 1944. (47)

Treatment	*To Supply*		*Yield—Pounds per acre*	
Method and time of application of materials and rate in pounds per acre	*Calcium*	*Magnesium*	*Location* I*	II**
	Pounds CaO per Acre	*Pounds MgO per Acre*		
No treatment	—	—	74	889
Broadcast February 15				
Dolomitic limestone 1974	600	430	928	1515
Calcitic limestone 1074	600	—	1174	2008
Dolomitic limestone 1316	400	286	533	1541
In row at planting—April 25				
Dolomitic limestone 658	200	—	415	843
On row at emergence—May 14				
Landplaster 640	200	—	1644	1468
Burnt lime 200	200	—	808	1289
Dolomitic limestone 658	200	143	570	1011
Calcitic limestone 358	200	—	907	1618
Magnesium carbonate 300	—	143	47	694
On foliage—July 7				
Landplaster 600	200	—	1209	1907
L.S.D. .05	—	—	233	244
.01	—	—	313	329

*Norfolk sand; pH = 5.0; exchangeable soil calcium = 0.38.
**Norfolk loamy sand; pH = 5.0; exchangeable soil calcium = 0.46.

made between two or more calcium-bearing substances with little effort made to place the materials on a comparable basis . . . that is, to add equivalent amounts of calcium or to use quantities of liming materials of equal neutralizing power. Furthermore, many of the calcium materials are carriers of other elements which may also influence the experimental results. Despite these difficulties, from the existing knowledge of the use of liming materials and of the calcium needs of peanuts, it should be pos-

sible to predict the most effective means of supplying calcium to this crop.

On most soils it would appear to be better to meet the calcium needs of peanuts by liming materials rather than through the use of neutral calcium salts such as gypsum. With the possible exception of tobacco, most of the crops which might be grown in rotation with peanuts would benefit from the use of lime on the more acid soils. Furthermore, on very acid soils (below pH 5.0) peanuts themselves may respond more to liming materials than to additions of neutral calcium salts. For example, the

Courtesy North Carolina Agricultural Experiment Station (81)

Figure 4.—The response of Virginia Bunch peanuts to additions of one ton of dolomitic limestone. The stunted, light colored plants, were growing on soil at a pH of 4.7 and with 0.46 m.e. of exchangeable calcium.

response to lime may be evidenced by a darker, greener vegetation and an increase in plant size as shown in figure 4. The stunted, light-colored condition of peanuts on very acid soils is due in part to a deficiency of nitrogen, resulting from a reduction in activity of nitrogen-fixing microorganisms. Mann (69) has reported that the addition of lime to virgin Norfolk and Coxville soils (pH 5.3 and 4.5) resulted in a large increase in nodulation of peanuts while gypsum reduced the nodulation. In view of recent work (53, 77, 97, 113) with other legumes, the poor growth of peanuts on very acid soil may be due in part to a toxicity of such elements as manganese, iron and aluminum. Too, there is evidence (28, 39, 78)

that with certain plants calcium is not absorbed as readily in acid media as in those of a higher pH.

Peanuts are especially heavy "feeders" of potassium and the plant may absorb considerably more of this element than is needed. Certainly it would be desirable to reduce this luxury consumption of potash if the yields were not adversely affected. There is considerable evidence (86, 87, 93, 113) that the addition of lime to soils will result in a decreased absorption of potash by the plant. On the other hand, gypsum may increase the uptake of K (93, 113). The differential effect of the two materials upon potash absorption provides another point in favor of the use of limestone rather than gypsum for peanuts.

On soils of extremely low-exchange capacity, it may be necessary to apply a soluble source of calcium in addition to lime in order to supply adequate amounts of calcium.

Recent fundamental studies (37, 46) have emphasized the specific need of the peanut for calcium and have shown that cations of a similar nature, such as magnesium, cannot be effectively substituted for calcium. If the primary objective in using lime for peanuts is to supply the nutrient calcium, it should be desirable to use a material which would be most effective in meeting that need. When the soil pH is increased beyond a certain point by liming, certain minor-element deficiencies may be encountered. Thus there is an obvious limit to the amount of lime which may be safely used. Yet dolomitic limestone is used almost exclusively in some peanut-producing regions, and less than one-half the amount of calcium is supplied by this material in liming a soil to a given pH as would be added were calcitic limestone used. Therefore, from the standpoint of meeting the calcium requirements of peanuts, it should be more desirable to use a form of calcitic limestone rather than one high in magnesium.

Some soils used for the production of peanuts are low in magnesium, and the superiority of dolomitic limestone observed in certain experiments has undoubtedly been due to a magnesium response. However, the magnesium requirement of peanuts is relatively low and, on soils deficient in this element, it might be desirable to supply the needed magnesium in the fertilizer or to use a mixture of calcitic and dolomitic limestone. If such a mixture were used, it would appear to be desirable to keep the ratio of Ca to Mg in the liming material relatively high.

Placement of Calcium

Recent studies (40) have shown that much of the calcium absorbed by the peanut roots is immobilized in the leaves and stems, and insuf-

ficient quantities are normally translocated to the developing gynophores to insure well-developed kernels. The studies have further shown that calcium may be absorbed directly by the developing pods and have indicated that for proper kernel development it is very important that an adequate supply of calcium be present in the zone in which the fruit are formed.

By using a technique in which the runners on one side of the plant could "peg-down" in one medium and the fruit on the other side of the plant could develop in a different medium, Brady (36) was able to

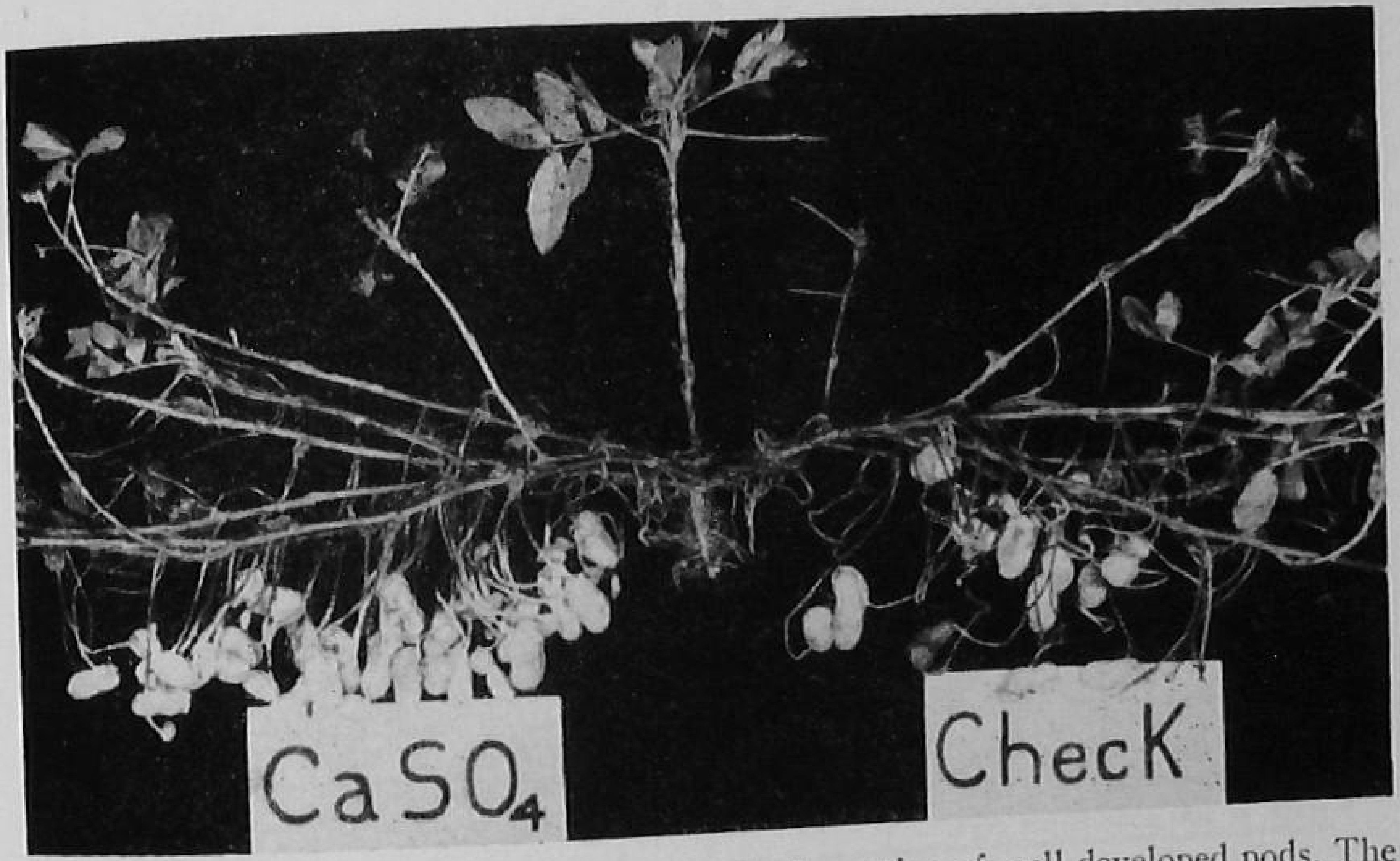


Figure 5.—The influence of gypsum upon the formation of well developed pods. The fruit on the left developed in a media supplied with a calcium sulfate solution, while those on the right were supplied with distilled water only. Brady (36).

demonstrate quite clearly the importance of proper placement of calcium. Figure 5 shows that an abundance of well-developed pods were formed on the side of the plant which had received calcium while relatively few healthy fruit were produced on the other side in a medium which had not been supplied directly with calcium. This work clearly shows that calcium is not readily translocated from one part of the plant to the other. Other data (table 6) reported by Colwell and Brady (45) demonstrate the importance of proper placement in the use of calcium-bearing materials for peanuts in a low-calcium environment. Gypsum supplied to the rooting zone did not adequately meet the demands of the developing fruit; however, large increases in shelling percentage and yield were observed when the gypsum was applied to the fruiting medium. Obviously, for

satisfactory kernel development, it is essential that calcium be supplied to the zone in which fruit are being formed.

The best method of applying gypsum to peanuts appears to be that of dusting the material on the plant at the early flowering stage. This relatively soluble source of calcium falls around the plant in the zone of pod formation and is present at the time when the need for calcium is the greatest. It is essential that the gypsum be well distributed throughout the zone of fruit formation. Since there is little residual effect of normal applications of gypsum (300 to 600 pounds per acre), it is necessary to make annual additions of this material.

Table 6.—Effect of Placement of Gypsum on Yield and Quality of Peanuts on Norfolk Fine Sandy Loam, Deep Phase, in 1942[a]. (45)

Gypsum application[b]	*Total fruit examined*	*Percentage fruit*		*True shelling Percent*	*Corrected Yield Pounds per Acre*	*Soil analysis*
		Well filled	*Half "pops"*			
None..........	2,057	9	12	24.9	364	pH = 6.1
Rooting medium.	2,915	19	24	40.5	878	Ex. Cap. = 2.10
Fruiting medium	2,593	49	15	52.9	1,595	Ex. Ca = 0.21
						Percent Ca Sat. = 10
L.S.D. (.05)....		6.8		7.3	310	Ex. Mg = 0.16
L.S.D. (.01)....		9.1		9.9	417	Ex. K = 0.06
						Percent O.M. = 0.8
						P, p.p.m. = 30

[a] Four replications
[b] Rate = 400 pounds per acre.

As shown in table 5, broadcast applications of lime may be as effective as gypsum in meeting the calcium requirements of peanuts. However, these and other data (18, 37, 45) generally indicated that lime applied in the row at planting may be inferior to gypsum. A satisfactory plan might be one in which 1,000 to 1,500 pounds of lime are applied broadcast to the peanuts every 2 to 4 years, the exact amounts and frequency of applications being governed by soil characteristics. It would appear to be best to broadcast the lime after the land had been turned but before the peanuts are planted. By so doing, more of the calcium is concentrated in the surface layer and hence should be more effective in supplying the needs of the developing pods. By applying relatively small amounts of lime in this manner immediately prior to peanuts in the rotation, it might be possible to maintain an adequate supply of calcium without increasing the pH beyond the level where certain minor-element deficiencies are encountered.

Effects of Soil Properties on Calcium Requirements

Several studies have indicated that the response of peanuts to calcium is governed to a large extent by certain soil properties. Attempts have been made to correlate the level of exchangeable calcium in soils with response to lime additions. Rogers (95) found that the response of peanuts to lime was related to the exchangeable calcium level of the soil and

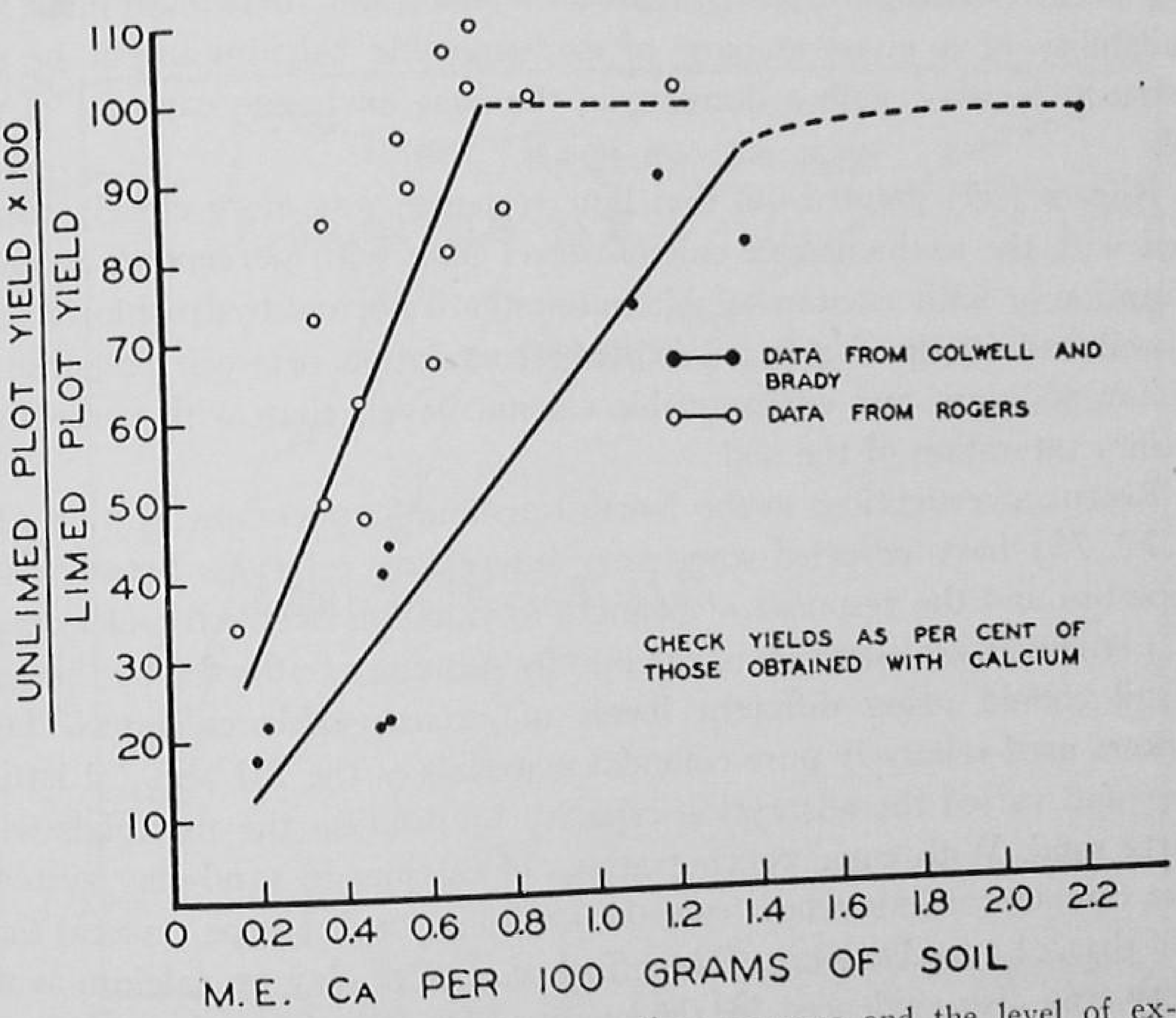


Figure 6.—The relationship between lime response and the level of exchangeable calcium in the soil. Work by Colwell and Brady (45) was conducted on Norfolk soils in North Carolina while data by Rogers (95) was obtained from work with Norfolk soils in Alabama.

indicated that the critical level of exchangeable calcium for peanuts on Norfolk soils in Alabama was between 0.6 and 0.8 m.e. per 100 grams of soil. Colwell and Brady (45) also observed a correlation between the exchangeable calcium level of soils in North Carolina and the response of peanuts to additions of lime. The relationships between the lime response and exchangeable calcium level as reported by Rogers and by Colwell and Brady are shown in figure 6. It is interesting to note the differences in the data obtained by investigators in the two States. Little response resulted from liming soils in Alabama which contained more than

0.7 m.e. of calcium per 100 grams. However, lime response was observed on North Carolina soils with calcium levels up to approximately 1.4 m.e. Two factors may have contributed largely to these differences: First, small-seeded varieties of peanuts were grown in Alabama while the large-seeded types were used in the work in North Carolina. It has been suggested that large-seeded peanuts have a greater need for calcium than the small-seeded type. Second, the peanut soils in Alabama are generally of a lower exchange capacity than those used in North Carolina. The availability of a given amount of exchangeable calcium might be expected to increase with a decrease in the base exchange capacity of the soil.

Rogers (95) pointed out that lime response was more closely correlated with the exchangeable calcium level than with percentage calcium saturation or with calcium soluble in one-tenth normal hydrochloric acid. Colwell and Brady also found a better correlation between response to calcium additions and exchangeable calcium levels than with percentage calcium saturation of the soil.

Recent investigations at the North Carolina Experiment Station (17, 18, 72, 73) have revealed some very interesting relations between soil properties and the response of peanuts to calcium. Mehlich and Colwell (72) studied the absorption of calcium by peanuts as affected by the type of soil colloid using different levels of exchangeable calcium. These workers used relatively pure colloidal materials of the 1:1 and 2:1 lattice types and varied the adsorption capacity by diluting the materials with quartz sand. With equal concentrations of calcium in sand-clay systems more calcium was absorbed from the kaolonite or 1:1 type mineral than from the 2:1 type bentonite. The effect of type of clay on calcium availability was also evidenced by the quality of the fruit produced (figure 7). A high percentage of filled pods was produced on kaolonitic colloids even at relatively low calcium levels. In the bentonite systems larger amounts of calcium were required to produce fruit of similar quality. These workers observed that the uptake of calcium from kaolonite systems was more directly related to the total calcium present than to the degree of saturation. In the systems of 2:1 type mineral the absorption of calcium was found to be more directly related to the percentage calcium saturation than to the total amount present.

In a later investigation Mehlich and Reed (73) studied the behavior of peanuts grown in systems in which the cation-adsorption capacity was due to both organic and mineral colloids. Kaolonite, bentonite and muck were used to prepare colloid-sand systems with different cation-ad-

sorption capacities, different exchangeable calcium levels and different percentage calcium saturations of the exchange complex. It was found that at any given level of exchangeable calcium, the quality of fruit was lower when produced in bentonite or muck. At any given cation-adsorption capacity the percentage of well-filled pods increased with an increasing degree of calcium saturation. Yet, when the percentage calcium saturations were of the same order the higher calcium levels produced the better quality of fruit. These workers pointed out that both the per-

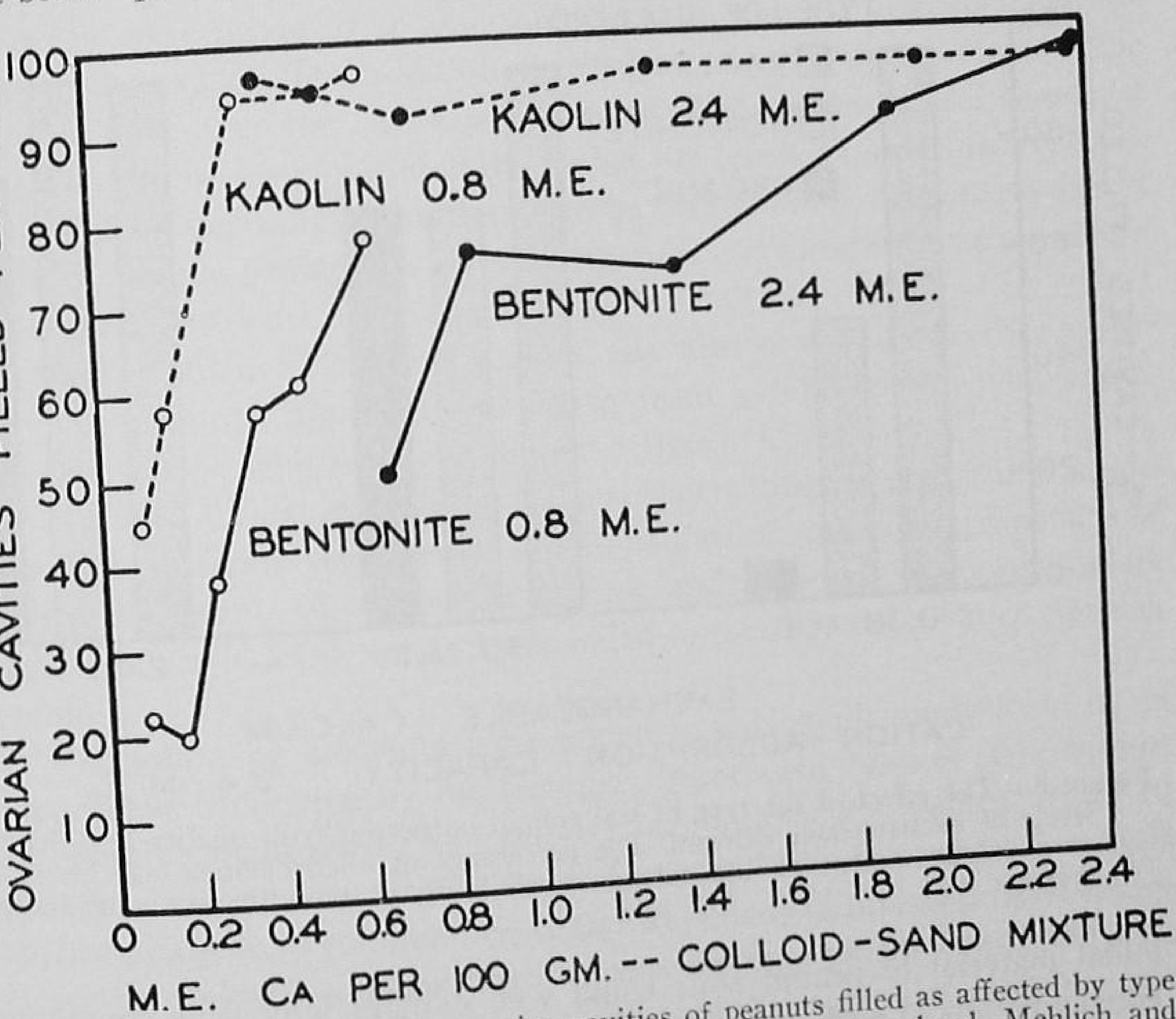


Figure 7.—Percentage ovarian cavities of peanuts filled as affected by type of colloid, cation-adsorption capacity and calcium level. Mehlich and Colwell (72).

centage calcium saturation and calcium level would have to be considered in determining the need for calcium in peanut soils.

A comparison of the relative availability of calcium in soils of different types of colloids is shown in figure 8. Using the percentage of filled nuts as a criterion of calcium availability, it is evident that a small amount of calcium is much less effective in a soil high in organic colloids than in a soil in which the cation-adsorption capacity arises from kaolonitic-type minerals. Furthermore, it is evident that greater amounts of calcium

would be needed for the production of good quality peanuts in soils high in organic matter or in those containing a large percentage of 2:1 type minerals.

Studies by Mehlich and Reed (73) of a number of surface soils from the Coastal Plain areas of North Carolina have indicated that the cation-adsorption capacity due to organic fraction of the colloids varied between 8 and 70 percent of the total. Such differences in the nature of the colloidal material in peanut soils could well explain why soils containing equal amounts of exchangeable calcium do not respond in a like manner to additions of calcium materials. Apparently the response of peanuts to amendments of calcium is influenced greatly by the type of soil colloid and the percentage calcium saturation as well as by the level of exchangeable calcium.

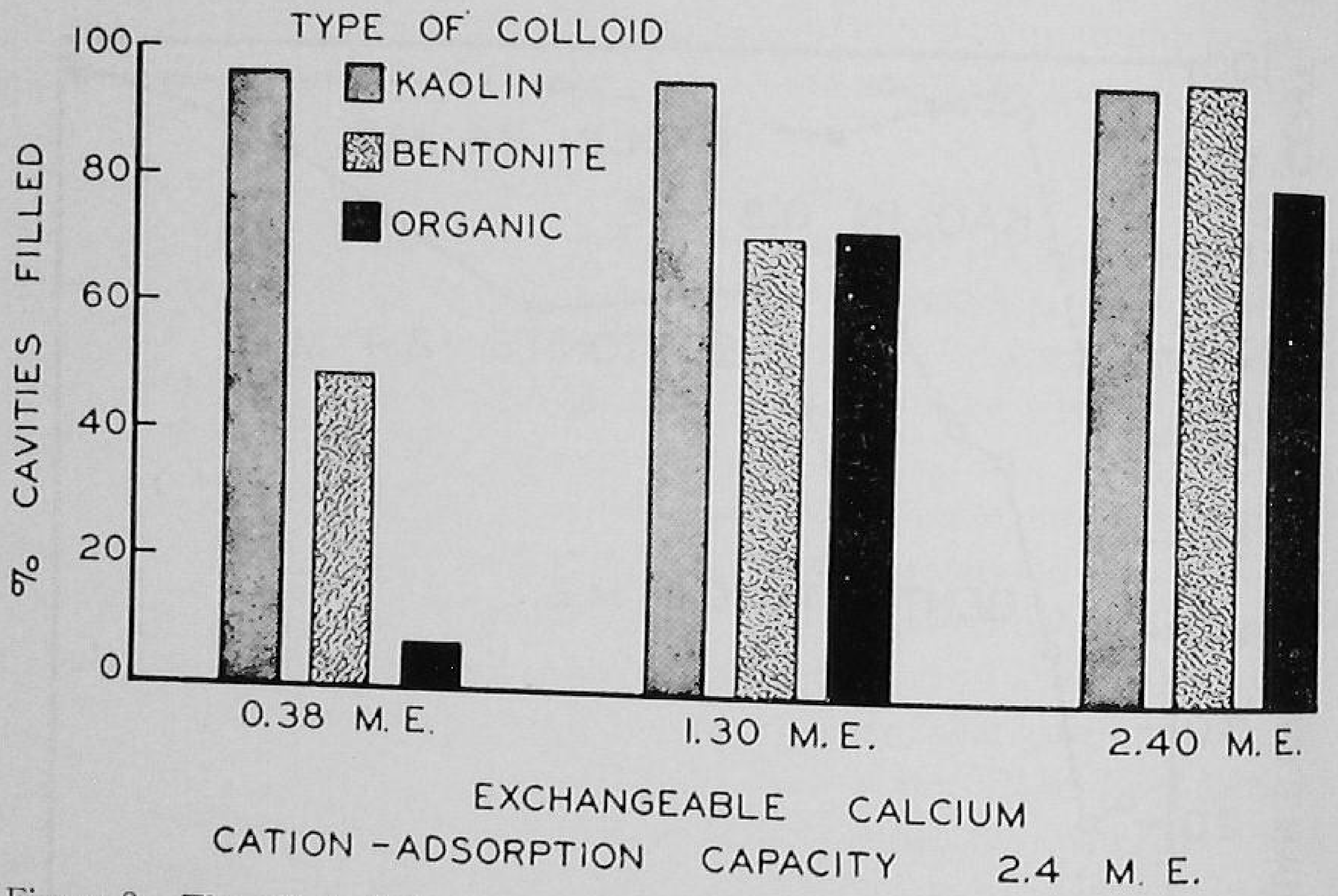


Figure 8.—The effect of the type of soil colloid on peanut fruit quality at different levels of exchangeable calcium. The percentage of filled cavities may be taken as a relative index of the calcium availability in the different sand-colloid systems (94).

MINOR ELEMENTS

Experiments conducted by several of the southeastern experiment stations have failed to show any widespread response of peanuts to additions of different "secondary" and "minor" elements.

There is some evidence that certain minor-element deficiencies may oc-

cur on soils which have been heavily limed. Batten (29) reported that peanut yields were reduced by applications of 2,700 pounds of lime, and recently Shear and Batten (99) initiated a study to determine the cause of poor growth and a chlorotic condition of peanuts grown on sandy soils which had been heavily limed. These workers found that the yields of peanuts on heavily limed soils were increased by the addition of 20 pounds per acre of $MnSO_4$ applied as a side dressing in June or by a broadcast application of 300 pounds of sulfur before planting. The yield increases were found to be associated with an increase in manganese uptake in both cases. The addition of manganese was found to increase the yield of nuts over the entire pH range studied; however, the beneficial effect was most pronounced at the higher pH levels (approximately 6.9). The shelling percentage was found to be decreased by manganese due to the fact that the growth period was extended, resulting in more immature nuts at harvest time.

Nelson (81), in North Carolina, has also observed "overliming injury" in peanuts, apparently resulting from a deficiency of manganese. An example of such injury is shown in figure 9.

Workers (1) at the Alabama Experiment Station report that applications of different combinations of 10 pounds of zinc sulfate, 5 pounds of borax, 25 pounds of manganese sulfate, and 5 pounds of copper sulfate per acre to a Norfolk sandy loam failed to increase the yield of Spanish peanuts.

The following elements were added to a Norfolk sandy loam in an experiment conducted by the Georgia Experiment Station (6): Sulfur, 40 pounds; manganese, 25 pounds; magnesium, 75 pounds; zinc, 10 pounds; copper, 10 pounds; boron, 5 pounds*. None of these materials applied alone or in combination with 500 pounds of limestone gave an increase in yield of nuts or hay. In another experiment conducted in a "sulfur-deficient area," Futral (6) reported that sulfate of ammonia was superior to nitrate of soda for Spanish peanuts and suggested that this superiority was due to a sulfur response.

A summary of experiments conducted on several soils in north Florida (5) shows little effect of additions to peanuts of a minor element-mixture containing 10 pounds of copper sulfate; 10 pounds of magnesium sulfate; 5 pounds of zinc sulfate; and 5 pounds of borax. Harris (57) has recently reported that peanuts grown on an Arredondo loamy fine sand in Florida developed abnormal characteristics which were corrected by

*The rates reported in this experiment were probably for the salt containing the element rather than the amount of the element itself, a possible exception being sulfur.

Courtesy North Carolina Agricultural Experiment Station (81)

Figure 9.—"Overliming injury" with peanuts, resulting apparently from a deficiency of manganese. The stunted, chlorotic plants in the center of the picture were growing on soil at pH 7.7 while the soil in the surrounding area was at pH 5.9. Such injury has been observed on soils as low as pH 6.4.

additions of copper to the soil. Applications of 10 pounds per acre of cupric chloride to the soil were found to increase the yield of both nuts and foliage and improved the grade quality of peanuts.

Collins and Morris (43) report that tests with iron, magnesium, copper, borax, manganese and zinc in 12 experiments in North Carolina over a 3-year period show little evidence that these elements were limiting factors in the production of peanuts.

Piland, Ireland and Reisenauer (88) studied the effect of additions of 5 pounds of borax on the quality of peanuts at 17 different locations in North Carolina. The average of the results showed that boron had a slight tendency to reduce the shelling percentage. However, the percentage of large nuts was increased significantly by the addition of borax.

Sommer and associates (101, 102) in greenhouse studies with several

Alabama soils observed marked increases in nut production from the use of magnesium. However, the soils had been subjected to very intensive cultivation prior to planting peanuts, and the responses were undoubtedly exaggerated because of abnormally low magnesium levels. These workers reported that little benefit was obtained from the addition of minor elements to peanuts.

VARIETAL DIFFERENCES IN RESPONSE TO FERTILIZATION

Many studies have indicated that peanut varieties exhibit marked differences in response to fertilization. Several workers (10, 106) have suggested that the so-called small-seeded types were more responsive to additions of N, P and K, whereas the large-seeded types might be expected to respond more to Ca amendments. However, there appear to be decided differences in the nutritional requirements of *varieties within* either of the different major types. Such differences might limit broad generalizations regarding the response of any given type of peanut to fertilization.

McClelland (68), in Arkansas, reported the results of experiments in which a number of different varieties and strains of the major types of nuts were grown with and without additions of limestone. The results are shown in table 7. Strains of Spanish peanuts were found to differ greatly in response to lime. Greater increases in yields of hay and nuts were obtained with improved Spanish and Spanish Selection than with any of the small runner or large-seeded types. The yield of Virginia Jumbo, a large-seeded type, was initially very high and was slightly reduced by the lime.

The 5-year average results of an experiment conducted on a Norfolk sand at the Florida Experiment Station (65) are shown in table 8. Several different varieties and strains of both the large- and small-seeded type peanuts were grown with and without additions of 600 pounds of gypsum. The average results show little response of small-seeded varieties or of Virginia Bunch, a large-seeded variety, to this calcium-bearing material. The yields of Jumbo variety were increased by adding gypsum, while this material tended to decrease the yields of Virginia Runner, also a large-seeded type. Therefore, although one of the large-seeded varieties appeared to benefit from the gypsum, it is not possible to conclude from this experiment that, as a group, the large-seeded peanuts were any more responsive to amendments of calcium than were the small-seeded varieties.

Table 7.—EFFECT OF LIME UPON YIELDS OF SEVERAL VARIETIES OF PEANUTS. ARKANSAS EXPERIMENT STATION,[d] 1940. (68)

Variety and treatment	*No Lime*		*Lime*[a]		*Gain with Lime*[c]	
	Peanuts per acre	*Hay*[b] *per acre*	*Peanuts per acre*	*Hay per acre*	*Peanuts per acre*	*Hay per acre*
	Pounds	*Tons*	*Pounds*	*Tons*	*Pounds*	*Tons*
Spanish	3,353	3.76	3,564	4.29	211	0.53
Improved Spanish	2,508	2.90	4,462	5.94	1,954	3.04
Spanish Selection	2,429	2.71	4,488	5.28	2,059	2.57
Red Spanish (1)	2,429	2.71	3,221	3.70	792	0.99
Red Spanish (2)	3,036	3.37	3,300	3.63	264	0.26
Valencia	2,561	2.84	2,851	3.23	290	0.39
Tennessee Red (1)	1,716	2.11	2,376	3.04	660	0.93
Tennessee Red (2)	3,300	4.22	3,828	5.08	528	0.86
Virginia Red	2,112	2.51	3,168	3.96	1,056	1.45
White Virginia	528	.79	1,584	2.05	1,056	1.26
Virginia Jumbo	4,488	5.28	4,224	5.02	−264	−.26
Jumbo	2,006	2.77	2,719	3.43	713	0.66

[a] Applied in the row before planting at the rate of 880 pounds of air-slacked lime per acre.
[b] Hay yields include weights of nuts.
[c] No information was presented relative to the experimental design, replications, or the magnitude of differences which might be considered to be significant.
[d] Bolivar silt loam, pH = 5.42-5.65.

Table 8.—EFFECT OF GYPSUM ON YIELD OF SEVERAL PEANUT VARIETIES. NORFOLK SAND. FLORIDA AGRICULTURAL EXPERIMENT STATION. (65)

Variety	*5 Year Ave.*[b] *1923/24/25/26/28*		
	Gypsum[a]	*No Gypsum*	*Increase Over No Gypsum*
	Pounds per Acre	*Pounds per Acre*	*Pounds per Acre*
Spanish (Florida)	661	647	14
Spanish (Improved)	618	580	38
Valencia	591	552	39
Va. Bunch	994	930	64
Va. Runner[c]	801	950	−149
Jumbo	1,100	786	314
Fla. Runner	1,047	995	52

[a] Gypsum applied as top dressing at the rate of 600 pounds per acre as peanuts started to bloom.
[b] The 1927 peanut crop was destroyed by rodents. Continuous peanuts on the same plots from 1923 to 1928. All plots planted to oats in fall of year and turned in spring several weeks before peanut planting.
[c] The Virginia Runner was not in the test in 1923 and consequently has a 4-year average.

Stokes and Camp (104), working in Florida, have reported that gypsum gave profitable increases in yields of Florida runner and a Jumbo variety, but not of the Spanish, Valencia and Virginia Bunch varieties.

Experiments conducted at several locations by workers at the North Carolina Station (46) show considerable differences in response of the large- and small-seeded type peanuts to additions of lime and gypsum. On soils extremely low in calcium, the Virginia Bunch variety, a large-seeded type, was found to respond more to additions of gypsum than a small runner and White Spanish varieties. On soils high in calcium the response was quite erratic and no general trends were observed.

A detailed study by Middleton, et al. (74) of the behavior of four varieties of peanuts as affected by calcium and potassium variables reveals some interesting variety-fertility interrelations. Some of the results of this study are shown in figure 10. It is evident that the relative behavior of the four varieties depended upon the fertilizer treatment. For example: Without treatment the Spanish varieties yielded highest and the Virginia Bunch yielded lowest. However, when all varieties received gypsum, the yield of Virginia Bunch was the highest. The authors concluded that the

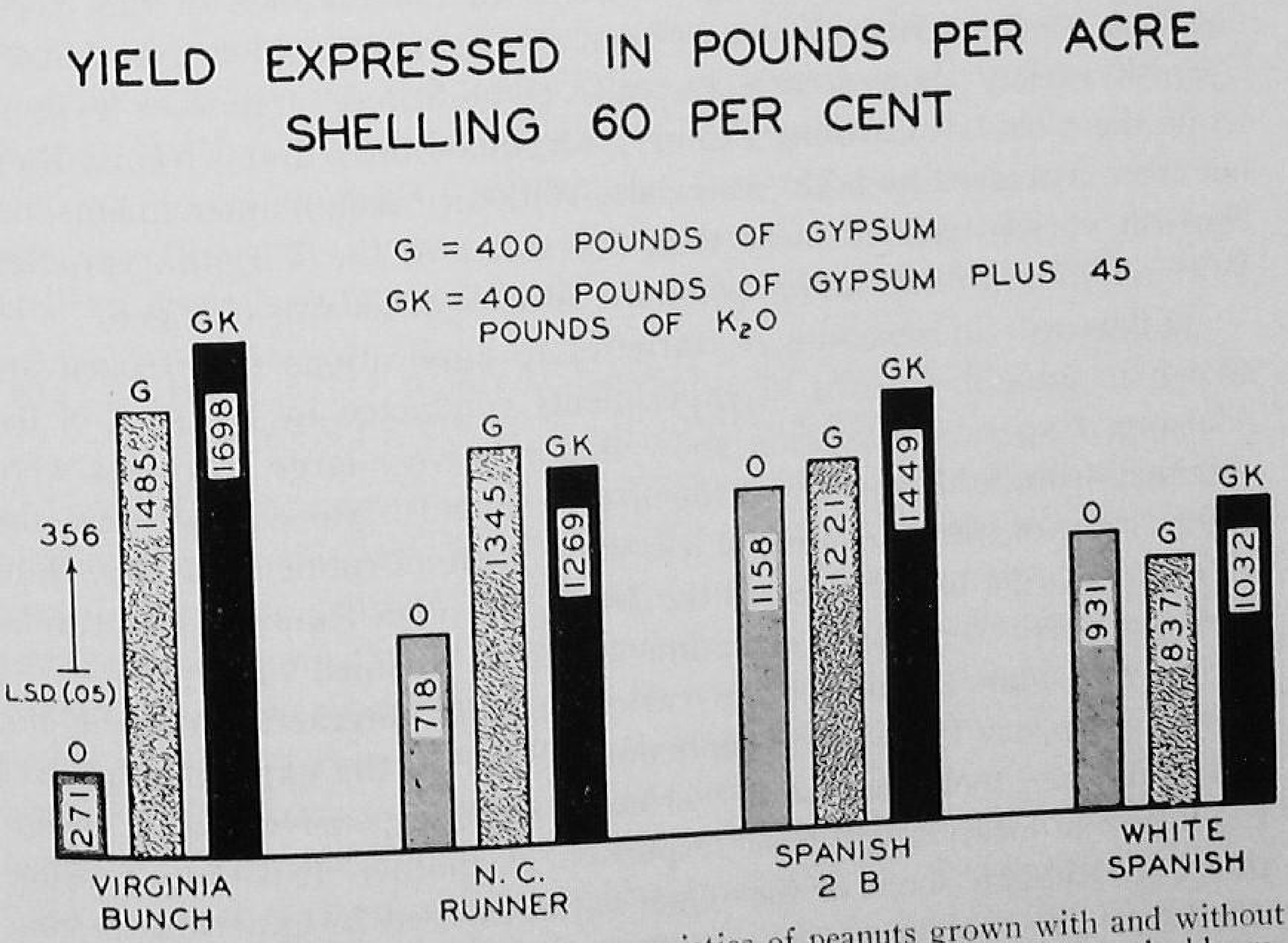


Figure 10.—The relative yields of four varieties of peanuts grown with and without amendments of gypsum and potash. Gypsum applied to foliage at early blooming; potash applied as top dressing at emergence. Soil, Norfolk sand; pH = 4.6; 0.54 m.e. exchangeable calcium; 0.04 m.e. exchangeable K. Source: Middleton, Colwell, Brady, and Schultz (74).

Spanish varieties might be better suited to soils low in calcium than the Virginia Bunch unless proper steps were taken to supply adequate calcium.

These workers at the North Carolina Station also point out that from one experimental location to another the effects of the fertilizer treatment on a particular variety were more consistent than the relative yields of the four varieties receiving the treatment. It was suggested that even when the calcium and potassium requirements were met some other factor apparently influenced the yield of one variety more than another. In view of the fact that the Spanish variety performed relatively better on soils with high organic-matter levels, it was suggested that there might have been a differential response to nitrogen.

Middleton and Farrior (75) reported that the Virginia Bunch variety performed better on some North Carolina soils than did the Jumbo Runner, whereas the reverse was true on other soils. These workers also observed that the large-seeded varieties appeared to respond more to the use of gypsum than did the small-seeded types.

The results of experiments conducted on a Norfolk loamy fine sand in Georgia are generally in agreement with the findings of the North Carolina workers. Investigators (6) at the Georgia Station found that a Spanish variety showed little response to additions of lime or gypsum while the yields of Carolina Runner, Virginia Bunch and Virginia Runner were increased by both materials. Without calcium amendments, the Spanish variety yielded more than did either of the Virginia varieties. With additions of lime and gypsum the relative order was changed.

Differences in response of varieties to applications of nitrogen are shown in table 3. Results of experiments conducted by the staff of the Alabama Experiment Station show that relatively large increases were obtained from additions of nitrogen to a Spanish variety, whereas the higher rates of nitrogen were of less value with a "runner" variety. Gore (55) in Georgia has also found the North Carolina Runner peanut to be less responsive to nitrogen amendments than a Spanish variety.

At first glance some of the variety-fertility interaction data in the literature appear to be quite anomalous. Some of the experimental data would indicate that one type or variety is most responsive to a given nutrient at one location and least responsive at another. It is quite possible that even though some of the older varieties used in experiments conducted at different locations were the same in name, they may have been distinctly unlike genetically. If such genetic differences did exist, it should not be surprising if the behavior were not the same in view of the marked

differences in lime response which have been observed with strains of the same variety (table 7).

Some of the experimental evidence might suggest that the differences in response of varieties or types of peanuts to fertilization are, to a certain extent, a function of seed size. Such may be the case, or the unequal response to fertilization may be due to other genetic differences not associated with kernel size. At any rate, it is fallacious to attempt to classify all peanut varieties in two categories, a large-seeded group and a small-seeded group, because of the gradation in kernel size, with no sharp differentiation which would permit such broad groupings. Certainly the differences in seed size and behavior of peanut varieties within either of the so-called major-size groups would limit generalizations as to their responsiveness to fertilization.

Considering the differences in varietal response to fertilization, it is very evident that research programs in peanut breeding and soil fertility should be inseparable. In comparative tests of several varieties, it has been demonstrated that an apparently superior variety may be definitely inferior under different environmental conditions. Therefore, in evaluating peanut varieties, it is essential that they be grown at different levels of soil fertility and under other variations in environmental conditions. The fact that many of the present peanut varieties appear to be relatively unresponsive to fertilization does not preclude the possibility that varieties may eventually be developed which would respond to fertilizer amendments much in the same manner as do many other crops.

ROTATION AND MANAGEMENT PRACTICES AND THE MAINTENANCE OF SOIL FERTILITY

Several factors combine to make the problem of maintaining the fertility of peanut soils especially acute. First, the native fertility of the soils used for growing peanuts is relatively low. Furthermore, peanuts remove relatively large amounts of certain nutrients from the soil with the normal systems of management in which both hay and nuts are harvested. Since peanuts have not been found to be as responsive to direct applications of fertilizer materials as are many other crops, there is a tendency to supply much less of certain nutrients than is removed from the soil by the crop. Considering these factors, the problem is resolved to one of determining the most effective and economical manner of obtaining high yields of peanuts and other crops grown in rotation with them and, at the same time, maintaining the fertility of the soil.

Continuous Cropping With Peanuts

Farmers have long recognized the fact that it is not desirable to plant peanuts year after year on the same soil. The harmful effect of continuous cropping with peanuts was aptly illustrated in a study conducted at the Georgia Coastal Plain Experiment Station (table 9). In an experiment in which continuous peanuts were fertilized with different combinations of N, P and K it was found that with all fertilizer treatments there was a progressive decline in yields with each successive crop of peanuts. There was little effect of withholding nitrogen or phosphorus from the complete

Table 9.—The Yields of Successive Crops of Peanuts Grown with and without Addition of Fertilizers. Georgia Coastal Plain Experiment Station (11).

Treatment[a]	*Yield unshelled nuts per acre*				
	1940	*1941*	*1942*	*1943*	*1944*
	pounds	*pounds*	*pounds*	*pounds*	*pounds*
No fertilizer	1407	1259	804	663	488
0-8-8	1645	1585	1169	1088	1037
3-0-8	1744	1647	1303	1125	1106
3-8-0	1628	1410	1013	910	531
3-8-8	1701	1603	1272	1150	1075

[a] 500 pounds fertilizer per acre.

fertilizer; however, the yields were markedly reduced when no potassium was added. Apparently the lack of potash was the factor primarily responsible for the poor yields on the nonfertilized soil. Perhaps the yields could have been maintained at higher levels on the plots receiving the complete fertilizer had more than 40 pounds of potash been applied.

Work conducted at the Alabama Experiment Station (2) further demonstrates the harmful effect of planting peanuts continuously on the same soil. It was found that the yield of cotton planted after 7 successive years of peanuts was only 345 pounds despite the fact that the cotton received 600 pounds of 6-8-8 fertilizer. At the same time, plots which had been planted to continuous cotton during this period and fertilized with 600 pounds of 6-8-4 yielded 1,269 pounds of seed cotton. Peanut yields apparently had begun to decline also after 6 years of continuous cropping with peanuts.

It would indeed be difficult to maintain the fertility of peanut soils through such a program of continuous cropping and inadequate fertilization. There is no evidence, however, which would indicate that the

productivity of peanut soils could not be maintained if sufficient fertilizers are supplied to compensate for the nutrients removed by the crop. Yet, such a program of continuous cropping and heavy fertilization would undoubtedly not be economical. Furthermore, even though the fertility could be maintained, it would not be advisable to make successive plantings of peanuts on the same land because of the likelihood of more severe disease and insect infestation.

Crops Grown in Rotation With Peanuts

A number of crops such as corn, cotton, tobacco, soybeans, potatoes, grain sorghum, truck crops, cereals and legumes are well suited for use in rotations with peanuts. While there is little information relative to rotation requirements, it is generally recommended that peanuts not be grown on the same soil more than once every 3 or 4 years.

Beattie and Beattie (33) of the U. S. Department of Agriculture have suggested that peanut rotations should include at least two soil-building crops, one of which is a winter cover crop. Batten (30) considers the chief requirement of a peanut rotation to be that it should furnish a considerable amount of organic matter to be incorporated with the soil. Gore (54) at the Georgia Experiment Station reports that peanuts do especially well following well-fertilized cotton, tobacco or truck crops. This investigator reports that the only objection to rotating cotton with peanuts is the tendency for *Sclerotium rolfsii* to be more severe. It was reported that growers also found considerable disease in peanuts following cowpeas. The North Carolina Station has recommended that peanuts should not follow soybeans on soils where *Sclerotium rolfsii* is present.

The majority of the experimental work with peanuts indicates that little response may be expected from fertilizing peanuts if they are grown in rotation with other well-fertilized crops. The results from five rotation experiments conducted in North Carolina (19, 20) for a period of 6 years show that the application of 100 pounds of muriate of potash to cotton preceding peanuts resulted in as high peanut yields as did the application of 50 pounds to each crop. Furthermore, the yields of cotton were increased upon receiving all of the potash. The result of these and other (16, 18, 100) experiments suggests that instead of fertilizing peanuts directly it would be better to use relatively large amounts of fertilizers with other crops in the rotation which would respond to the additional fertilizer.

Experiments conducted by the Alabama Station (2) indicate that the normally recommended rates of fertilizing a crop such as cotton are inade-

quate when the crop is grown in rotation with peanuts. The results of experiments, reported in table 10, show that when two crops of peanuts were harvested during a 7-year period in a corn, cotton, peanut rotation, the fertility of the soil was depleted to such extent that the cotton yields were approximately one-half of those obtained on soil which had been planted to continuous cotton. The injurious effect of the two harvested crops of peanuts was overcome somewhat by applying more potash to the cotton.

Table 10.—THE INFLUENCE OF PEANUTS IN A ROTATION WITH COTTON AND CORN UPON THE YIELDS OF COTTON. ALABAMA AGRICULTURAL EXPERIMENT STATION (2).

Year[d]	*Yield of cotton in corn, cotton, peanut rotation*[a]	*Yield of cotton in corn, cotton, peanut rotation*[b]	*Yield of cotton in a continuous cotton rotation*[c]
	Pounds per acre	*Pounds per acre*	*Pounds per acre*
1933	1696	1622	1406
1936	1368	1298	1366
1939	652	1075	1269

[a] Cotton fertilized with 600 pounds 6-8-4; corn and peanuts unfertilized.

[b] Cotton fertilized with 600 pounds 6-8-4 in 1933 and 1936; 600 pounds 6-8-12 applied to cotton in 1936. Corn and peanuts unfertilized.

[c] Cotton fertilized yearly with 600 pounds 6-8-4.

[d] The experiment was initiated in 1932.

LEGUMES AND NONLEGUMINOUS COVER CROPS IN PEANUT ROTATIONS

Very little plant residue is returned to the soil from a crop of peanuts; thus, as normally harvested, peanuts remove considerable quantities of inorganic nutrients. Furthermore, when peanuts are harvested the soil is left completely bare for several weeks during late summer and fall, providing conditions favorable for the rapid oxidation of the soil organic matter. Certainly it would be difficult to maintain the productivity of peanut soils unless measures were taken to replenish the supply of organic matter. Green manure crops are well suited to peanut rotations and their use may help maintain an adequate level of organic matter in soils.

Numerous experiments have been conducted to determine the effect of legumes and nonleguminous cover crops upon the yield of peanuts. Investigators at the Alabama Station (1) have studied the effect of vetch and oats upon the yield of continuous peanuts, and the results are reported in Table 11. These data show that the addition of phosphorus and potash to peanuts resulted in a 50-percent increase in yields. When vetch was grown and fertilized with P and K, the yields of peanuts were more

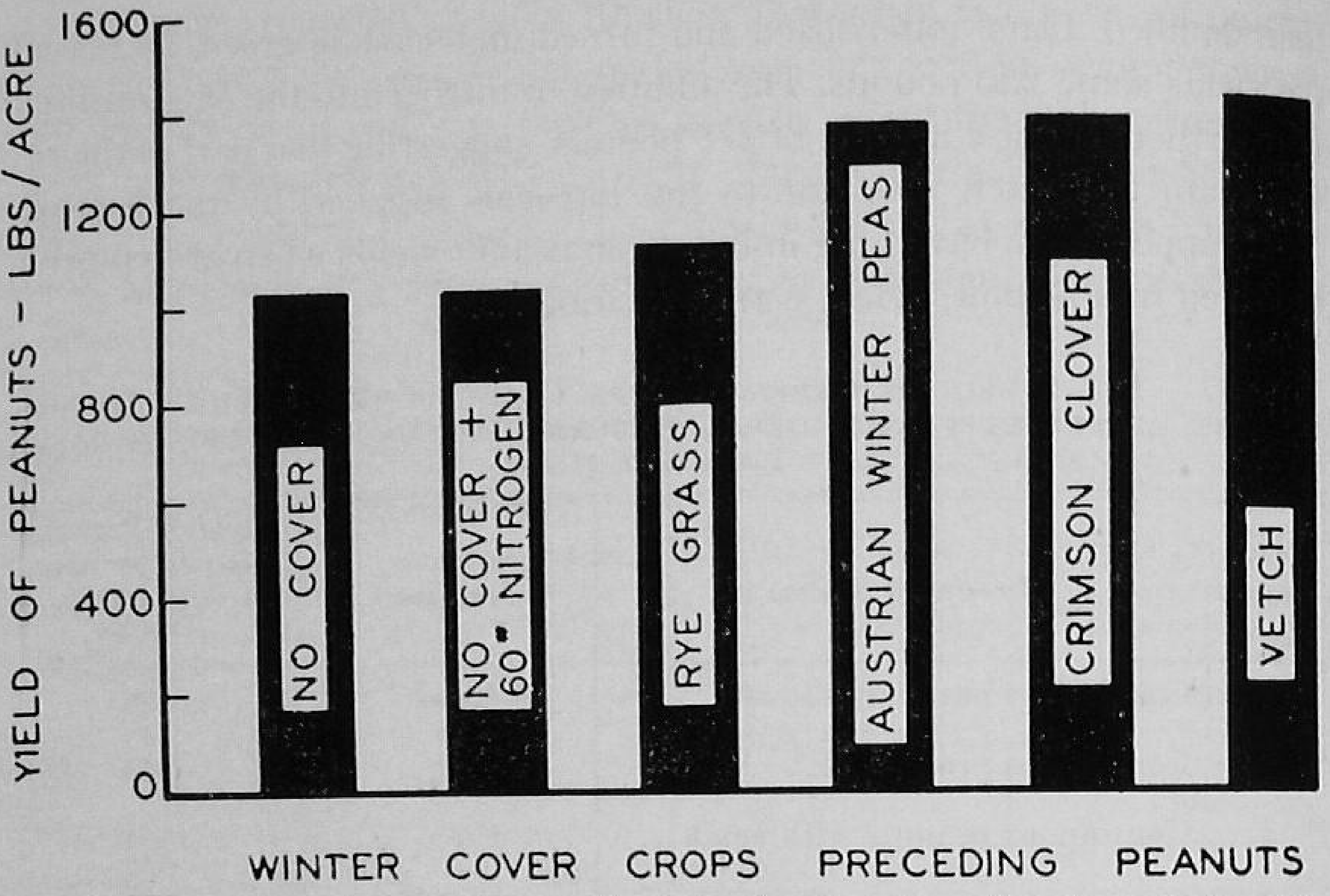
than doubled. Oats, unfertilized and turned under while green, increased the yields some 250 pounds. The addition of nitrogen to the oats resulted in a further increase in yield of 275 pounds, suggesting that part of the response to the vetch was due to the nitrogen supplied by the legume. Vetch appeared to have little influence on peanut yields when grown prior to cotton in a peanut, vetch, cotton rotation.

Table 11.—THE EFFECT OF GREEN MANURE CROPS ON THE YIELD OF SPANISH PEANUTS. EXPERIMENTS CONDUCTED AT AUBURN, ALABAMA, ON A NORFOLK SANDY LOAM SOIL (1).

Number	*Cropping System*	*Fertilizer*[a]	*Yield of Peanuts pounds per acre 4-year average 1943-46*
1	Continuous peanuts	None	626
2	Continuous peanuts	P-K	985
3	Continuous peanuts with vetch	P-K	1364
4	Continuous peanuts	N-P-K	972
5	Continuous peanuts with oats as green manure crop	None	851
6	Continuous peanuts with oats as green manure crop	N	1121
7	2-year rotation—cotton peanuts	P-K P-K	1094
8	2-year rotation—cotton peanuts vetch	P-K P-K P-K	1095

[a] N = 36 pounds nitrogen from nitrate of soda.
P-K = 300 pounds 0-14-10 per acre.

Workers (15) in North Carolina have studied recently the effect of several different cover crops upon the yields of peanuts in a cotton-peanut rotation. The results are shown in figure 11. The legumes were found to increase the yields of peanuts an average of 40 percent. It was concluded that the increase was not due to the nitrogen supplied by these crops since the yields of the "no-cover" plots were not affected by the addition of 60 pounds of nitrogen. Yet, as seen in figure 11, ryegrass was not as effective as were the legumes. These investigators indicated that turning under large amounts of winter cover crops prevented packing and left the soil in better physical condition. Penetrometer measurements indicated that the soil in the vetch plots was more easily penetrated than in the "no-



Courtesy North Carolina Agricultural Experiment Station (15)

Figure 11.—The effect of different winter cover crops upon the yield of Virginia Bunch peanuts. (3-year average).

cover" plots. It is essential that peanut soils be in good physical condition because the pegs must penetrate the surface soil in order for nuts to be formed.

Effect of Methods of Harvesting Peanuts on Soil Depletion and Growth of Succeeding Crops

A large percentage of the peanuts grown in the United States is harvested for market by removing both nuts and vines from the soil. As discussed previously, such a system of management is known to remove large quantities of nutrients and to lower the productivity of the soil. In some sections of the Southeast, the practice of harvesting the peanut crop by grazing hogs (hogging-off) is followed. With such a practice most of the nutrients are returned to the soil in the plant residues and animal manures. Peanuts handled in this manner may serve as a soil-building crop.

Results of studies conducted at the Wiregrass Experiment Station in Alabama with different cropping systems including hogged and dug peanuts are shown in table 12. Peanuts planted continuously on the same soil, unfertilized and harvested by hogs, were found to yield quite satisfactorily . . . as well, in fact, as those grown in rotation with fertilized

Table 12.—YIELDS OF COTTON, CORN AND PEANUTS IN CROPPING SYSTEMS THAT INCLUDE HOGGED AND DUG PEANUTS. WIREGRASS SUBSTATION, HEADLAND, ALABAMA, 1939-1946, INCLUSIVE (1).
TIFTON FINE SANDY LOAM

Cropping system	*Crop*	*Fertilizer*[a]	*Average Yield 1939-46* Pounds seed cotton and peanuts, Bushels corn
1	Peanuts—Dug	0	602
2	Peanuts—Hogged	0	1524
3	Peanuts—Dug	0-8-8	1455
	Cotton	6-8-8	975
4	Cotton	6-8-4	1207
	Peanuts—Dug	0-8-4	1627
5	Cotton	0-8-4	1380
	Peanuts—Hogged	0	1791
6	Cotton	6-8-4	1416
7	Corn	0	10.0
8	Corn	6-8-4	33.3
9	Corn	0-8-4	23.0
	Peanuts—Dug	0-8-4	1640
10	Corn	0-8-4	40.6
	Peanuts—Hogged	0-8-4	1777
11	Corn	0	42.1
	Peanuts—Hogged	0	1744
	Cotton	6-8-4	1384
12	Peanuts—Dug	0	1507
	Corn	0	20.6
	Cotton	6-8-4	799
13	Peanuts—Dug	0	1566
	Corn	0	25.6
	Cotton	6-8-12	1176

[a] 600 pounds per acre. Cotton received 6-10-4 and all other crops no fertilizer. 1932-1938.

cotton or corn and dug. Higher yields were obtained, however, when the hogged peanuts were grown in rotation with a fertilized crop of corn or cotton. The yield of corn grown in rotation with hogged peanuts was some 17 bushels greater than when rotated with dug peanuts. Cotton yields were also much greater in rotation with hogged peanuts. The

higher yields of crops following hogged peanuts were probably due in part to the nitrogen returned to the soil in plant residues.

Other experiments in Alabama (2) have shown that when peanuts were dug the yields of the succeeding crops were decreased, but when harvested by hogs the yields of the following crops were increased. Thus the method of harvesting may determine whether peanuts are soil depleting or whether they may actually increase the productivity of the soil.

Table 13.—INTERPLANTED CORN AND PEANUTS IN A CORN-COTTON ROTATION. ALABAMA AGRICULTURAL EXPERIMENT STATION (1).

Cropping[a]	*Yields per acre*		
	Seed cotton Pounds	*Corn Bushels*	*Peanuts*[b] *Pounds*
Brewton Field[c], *1938-1946*			
Cotton, corn	551	12.9	—
Cotton, corn and peanuts	741	11.8	394
Prattville Field[d], *1932-1946*			
Cotton, corn	597	13.7	—
Cotton, corn and peanuts	840	10.8	794
Tennessee Valley Substation[e], *1932-1945*			
Cotton, corn	1,129	27.8	—
Cotton, corn and peanuts	1,283	23.4	841

[a] All rows 3½ feet apart; alternate rows in corn, and peanuts. All fertilizers, 600 pounds per acre 0-10-4, applied to cotton.

[b] Runner peanuts all years—vines returned to the land at Brewerton and Prattville.

[c] Kalmia fine sandy loam.

[d] Greenville fine sandy loam.

[e] Dewey silt loam.

It should be pointed out that the differences in yields of crops following peanuts harvested by the two methods would undoubtedly be smaller were more fertilizer applied to the dug peanuts to compensate for the nutrients removed by the crop. Thus it appears likely that the productivity of these soils could be maintained to a large extent through adequate fertilization.

While the peanut is considered to be one of the most soil-depleting crops grown in this country, there is nothing unique in the ability of this crop to reduce the productivity of soils. Other crops would undoubtedly be equally as injurious were they harvested as peanuts normally are. In some sections of the world, notably in certain localities in Africa, the tops are left on the soils after the nuts are picked. When such a practice is fol-

lowed the problem of maintaining the fertility of peanut soils is much less acute. In view of the fact that a large percentage of the nutrients absorbed by the peanut plant is found in the tops (table 1), the removal of the hay from peanut soils becomes a questionable practice. This is especially true because the organic-matter level of many soils used for growing peanuts is critically low and could, in part, be replenished were the peanut vines returned to the soil.

The practice of interplanting peanuts with corn has been followed in some localities. One or both crops may be harvested for market or may be hogged-off. Experiments at three locations in Alabama were conducted to study the effect of interplanting corn and peanuts upon the yield of cotton and corn grown in a 2-year rotation. The results of these tests (table 13) show that the yields of cotton were higher following interplanted corn and peanuts than when grown after corn alone. Furthermore, the value of the interplanted corn plus peanuts was considerably greater than the corn grown alone. It should be pointed out that the greatest increases in cotton yields were observed at the two locations where the peanut vines were returned to the land.

SUMMARY

There appears to be universal agreement on what constitutes an "ideal" soil for growing peanuts. A soil well adapted to the production of this crop has been characterized by many as a well-drained, light-colored, loose, friable sandy loam, well supplied with calcium and with a moderate amount of organic matter.

A study of the soil-fertility investigations with peanuts reveals a multitude of inconsistencies. Many workers have indicated that the peanut plant is quite unpredictable in its response to fertilization. While such would often appear to be the case, it seems that many of the apparent anomalies associated with the fertilization of peanuts have arisen through failure to evaluate fully the environmental conditions under which the experiments were conducted. Furthermore, due consideration must be given to the unique growth and fruiting habits of the peanut in interpreting experiment results. Recent fundamental studies dealing with the nutrition of peanuts have been very helpful in interpreting some of the peanut fertility research data. More of such investigations are greatly needed.

Most southern experiment stations currently recommend that peanuts be grown following other well-fertilized crops. When such a practice is followed, much of the experimental evidence suggests that little may be gained from additions of nitrogen, phosphorus or potassium directly to

the crop. There is some evidence that certain varieties of peanuts may respond to relatively large additions of nitrogen, despite the fact that the crop is a legume. However, large quantities of nitrogenous fertilizers are not commonly applied to peanuts. Unless the crops grown in rotation with peanuts receive very liberal applications of potassium, it may be necessary to apply some fertilizers containing this element directly to the peanuts in order to obtain maximum yields and to maintain the fertility of the soil.

The importance of calcium in the nutrition of peanuts has long been recognized. Generally the response of peanuts to amendments of calcium has been more consistent than to additions of any other nutrient. Apparently one of the primary functions of calcium in peanut nutrition is to improve the quality of the nuts, or more specifically, to aid in the development of the kernel. The better quality of nuts grown in soils well supplied with calcium is evidenced by a lighter, firmer hull and few unfilled pods (pops).

One of the most common methods of supplying the calcium needs of peanuts is to apply gypsum to the foliage at early blooming. However, when the soil has been limed adequately little benefit may be derived from additions of gypsum. For a number of reasons, it would appear better to maintain an adequate calcium level in peanut soils through the use of a liming material rather than by additions of a neutral salt such as gypsum. Calcitic lime should be superior to one high in magnesium.

Some investigators have obtained a fair correlation between the exchangeable calcium levels in soils and the response of peanuts to amendments of lime or gypsum, and expected responses have been predicted on such a basis. However, for a more exact estimate of the need for calcium in peanut soils, the nature of the soil colloids and the percentage base saturation, as well as the exchangeable calcium level, need to be considered.

There is little evidence that any of the so-called "secondary" and "minor" elements are normally limiting the yield of peanuts, except perhaps on heavily limed soils where deficiencies of manganese may occur.

A review of peanut-fertilization research suggests that too little attention has been given to the method of placement of peanut fertilizers. Studies have shown that in order for calcium to be most effective it should be localized in the zone in which the pods develop. On the other hand, a high concentration of potassium in the fruiting zone may be harmful because of its effect on fruit quality, especially at low-calcium levels. Furthermore, fertilizer materials, if placed too close to the seed at

planting, may impair germination. Perhaps fertilizer materials would be found to be more beneficial if a greater effort were made to use them properly.

There is much evidence that peanut varieties exhibit marked differences in their response to certain nutrients. Furthermore, strains within a given variety have been found to differ greatly in response to fertilization. These differences may account in part for some of the existing confusion regarding the fertilization of peanuts. Certainly the plant breeder must give ample consideration to such differences in evaluating peanut varieties.

Peanuts remove relatively large amounts of certain nutrients from the soil with the normal systems of management in which both hay and nuts are harvested. Yet, because of the fact that peanuts have not been found to be as responsive to direct applications of fertilizer materials as other crops there is a tendency to supply less of some nutrients than is removed from the soil by the crop. It is by no means a desirable practice to grow peanuts continuously on the same soil. Many experiment stations recommend that they not be grown more than once every 3 or 4 years. Peanuts may be grown satisfactorily in rotation with a number of different crops. Generally, it would be desirable to grow well-fertilized crops such as cotton, tobacco or truck crops immediately prior to peanuts in the rotation.

Little organic matter is returned to the soil from a crop of peanuts. Furthermore, after peanuts are harvested conditions are quite favorable for the rapid oxidation of the organic matter present in the soil. Leguminous green manure crops are well suited to peanut rotations and their use may help to maintain an adequate level of organic matter and insure a good physical condition. It is especially important that peanut soils be kept loose and friable because the pegs must penetrate the surface in order for nuts to be formed.

With the normal methods of harvesting, peanuts are considered to be one of the most soil-depleting crops grown in this country. However, when the crop is harvested by grazing hogs or when the nuts are picked off and the vines returned to the soil peanuts may actually increase the productivity of the soil. Therefore, there appears to be nothing unique about the soil-depleting powers of the peanut as some have indicated.

It has been suggested (42) that large increases in peanut yields cannot be expected from fertilizer treatments as only the nuts produced in a relatively short period of continuous blooming of the plant can be saved at harvest. However, even though direct responses to fertilization

may not be pronounced, it is reasonable to expect increased yields of peanuts through the introduction of better varieties, by the more effective control of diseases and insect pests and through the adoption of better cultural practices such as the use of closer spacing. As such yield increases are realized and as more nutrients are removed from the soil by the harvested crop, the problem of maintaining the fertility of the peanut soils will undoubtedly become increasingly acute. It is likely that more fertilizers may eventually have to be applied to peanuts or to the other crops grown in the rotation if the productivity of peanut soils is to be maintained.

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CHAPTER VI

CULTURAL PRACTICES

By

D. G. STURKIE AND J. T. WILLIAMSON[1]

Research work involving some of the cultural practices with peanuts has been rather limited. Most of the experiment stations have conducted spacing tests; several have carried time-of-planting and seed-treatment tests; a few have studied seed preparation, seed types, and disease and insect control by dusting. However, the data on soil preparation, planting depths, cultivation, harvesting, curing, picking and perhaps other phases of this subject are either extremely meager or nonexistent. Station publications on many of these subjects carry only the authors' opinions. The authors of this chapter are in accord with most of these views, and, where data are not available, they have included such opinions as the best information obtainable on the subject.

PLANTING

Preparation of the Soil

There are very few data from controlled experiments with different methods of preparing land for peanuts. However, there is practically unanimous agreement among all research workers and extension agronomists that the land should be thoroughly and completely prepared before planting. Land is prepared for peanuts in much the same way as for cotton. Plowing is done early when there is no winter cover crop on the land. It is difficult to prepare land properly for peanuts if a large growth of residue from the preceding crop is turned under just prior to planting. For this reason plowing in the late fall or early winter is practiced frequently in order to permit complete decomposition of residues before time for planting. When a winter cover crop such as

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lupine or vetch is used, it is plowed under at least 30 days before peanuts are planted. In case weeds come up on the field, the land is disked to eradicate the weeds. The land is harrowed and dragged immediately before planting.

There are no data on depth of preparing the soil. Apparently, excessively deep preparation is to be avoided. Most lands should be prepared to a depth of from 5 to 7 inches.

Fertilizer Applications

Although the subject of peanut fertilization has already been discussed in Chapter V, brief comments are included here.

Many research workers have found that peanuts following a crop that was well fertilized with mineral fertilizers do not give increased yields from direct applications. However, it is still a general practice to apply fertilizers in the drill at planting and in some cases as top-dressing materials later in the season.

Fertilizers that are used in the drill are applied either to the side and slightly below the seed or well mixed with the soil so that they will not come in contact with the seed and thus reduce the stand. Many research workers recommend that fertilizers be applied 1 to 2 weeks ahead of planting.

In some sections it has recently become a common practice to apply fertilizers on the row just as the plants are emerging. This is especially true of potash materials. When this practice is followed the fertilizer is applied when the plants are dry in order to avoid burning. Cultivation with a weeder or rotary hoe should follow immediately so as to remove any fertilizer that may have come in contact with the plants. Batten (2) recommends that only concentrated potash salts be used in the fertilizer application made before planting because the use of a greater volume of the low-grade salts required to obtain the amount of potash needed often causes poor germination.

Use of gypsum on the foliage of large-type peanuts at blooming time has given outstanding increases in yields in North Carolina and Virginia. Experiments in other States have indicated little or no benefit from this practice when Spanish or the small runner-type peanut is grown. Studies have shown that gypsum is most beneficial if applied when the peanuts begin blooming. Gypsum has usually been dusted on the foliage by hand, but the use of machines for application is increasing.

Where limestone is applied in the drill before planting, it should be used as a separate treatment from the fertilizers that are applied at this

time. It is believed, however, that the best practice is to plant peanuts on land that has been adequately limed by previous broadcast applications.

Time of Planting

Throughout the greater part of the commercial peanut area, planting of the main crop is done between April 10 and May 10. Peanuts are planted from early March in parts of Texas and Florida to as late as June 15 in Virginia and North Carolina. The young peanut plant is capable of withstanding considerable cold. Therefore, peanuts may be planted earlier than cotton. The recommendations made by most agronomists are for planting at a reasonably early date. The best planting date is

Table 1.—Annual and Average Yields of Spanish Peanuts Planted at Different Dates, Lauderdale, Mississippi, 1940-1941[a]

Date of planting	*Yield per acre*		
	1940	*1941*	*Average*
	Pounds	*Pounds*	*Pounds*
April 15	1,550	920	1,335
May 15	1,200	860	1,030
June 15	1,356	610	983

[a] All plots received 400 pounds per acre of 0-8-4 with basic slag as a source of phosphorus; peanuts planted in 30-inch rows, 6 to 8 inches apart in the drill.

probably about 2 weeks after the average date of the last killing frost. Results of time-of-planting experiments show that farmers could very probably increase their yields by planting earlier than customary. In the Gulf Coast region, a fair yield may be expected from Spanish peanuts planted as late as July 1. Runner-peanut yields decline very rapidly as the date of planting is delayed.

Results from experiments on dates of planting in Mississippi (18) are given in table 1. These results show that yields from peanuts planted early are definitely higher than from peanuts planted at later dates.

Peanuts planted in April, May and June 1940-1943 at Rocky Mount, North Carolina (6) produced average yields of 1,215 pounds, 1,151 pounds and 710 pounds of nuts per acre, respectively. An exception to the above trend was noted in 1944 when slightly higher yields were obtained from the May than from the April planting.

Results of 10-year experiments at Tifton, Georgia (8), as shown in table 2, also indicate an advantage of early planting of both Spanish and runner peanuts.

Table 2.—AVERAGE YIELDS OF UNFERTILIZED PEANUTS PLANTED AT DIFFERENT DATES, GEORGIA COASTAL PLAINS EXPERIMENT STATION, TIFTON, 1934-1943.[a]

Planting date	*Yield of unshelled nuts per acre*	
	Spanish	*North Carolina Runner*
	Pounds	*Pounds*
March 15	1,388[b]	1,925[c]
April 1	1,338	1,860
April 15	1,335	1,804[c]
May 1	1,244	1,590
May 15	1,062	1,313
June 1	645	866

[a] No fertilizer used. Tests followed a general rotation of field crops.
[b] 8-year average, no data for 1934 and 1935.
[c] 9-year average, no data on March 15 planting in 1934 or on April 15 planting in 1943.

Yields from experiments conducted with Spanish peanuts at various Alabama locations are given in table 3. Except at Fairhope, where early plantings were damaged by rodents, these results also show a very definite advantage for early seeding. Planting at or about the last killing-frost date resulted in a good yield of peanuts. Slightly higher yields were obtained by delaying the planting 2 weeks after the last killing frost. Delaying the planting an additional 2 weeks, however, resulted in marked reduction in the yield.

In a date-of-planting experiment with runner peanuts at Auburn,

Table 3.—AVERAGE YIELDS OF SPANISH PEANUTS PLANTED AT DIFFERENT DATES AT VARIOUS LOCATIONS IN ALABAMA, 1943-1946

Location	*Years*	*Average yields per acre*[a]		
		1st planting[b]	*2nd planting*	*3rd planting*
	Number	*Pounds*	*Pounds*	*Pounds*
Fairhope	2	1,657	2,264	2,109
Prattville	3	1,096	981	840
Auburn	4	1,016	1,154	983
Alexandria	2	1,706	1,345	1,091
Crossville	4	1,699	1,729	1,562
Belle Mina	1	1,940	1,941	1,781
Average		1,426	1,477	1,305

[a] Yields are average of four plots; planting rate per acre 90 pounds of hand-shelled, and 60, 90 and 135 pounds of unshelled seed, respectively.

[b] Plantings made at approximately 15-day intervals, first planting at about the average date of last killing frost at each location and varied from March 9 at Fairhope to April 17 at Crossville.

Table 4.—Two-Year Average Yields of Runner Peanuts Planted on Norfolk Sandy Loam at Different Dates, Auburn, Alabama, 1945-1946[a]

Date of planting	*Yield per acre*
	Pounds
March 15	1,064
April 5	1,268
April 25	994

[a] 300 pounds per acre of 0-14-10 applied before planting; rows 30 inches apart; 90 pounds of unshelled seed planted per acre.

Alabama, the highest yield was obtained from the April 5 planting. The results are reported in table 4.

Runner peanuts were planted at 10-day intervals from April 5 to June 15, 1939-1946, inclusive, in a test at Prattville, Alabama. The average yields for all years are shown in table 5. Highest yields were obtained from planting on April 5. For some unexplainable reason, peanuts planted on April 15 produced less yield than those planted on either April 5 or 25 in 6 of the 8 years that the experiment was conducted.

Method of Planting

Peanuts are usually planted in a shallow furrow and are covered to a depth of 1½ to 3 inches on light soils and 1 to 2 inches on heavier soils. Under dry conditions, still deeper covering is recommended. After the seed are covered, the top of the seedbed is slightly below ground level. This allows early cultivation with a weeder or rotary hoe without danger of injury to young plants.

Table 5.—Average Yield of Runner Peanuts Planted at Different Dates, Prattville Experiment Field, Prattville, Alabama, 1939-1946[a]

Date of planting	*Yield marketable peanuts per acre*
	Pounds
April 5	1,570
April 15	1,417
April 25	1,498
May 6	1,346
May 17	1,260
May 25	1,166
June 5	1,051[b]
June 15	742[b]

[a] Rows 36 inches apart; hills spaced uniformly each year but varied from 8 to 12 inches from year to year. No fertilizers applied to peanuts.

[b] 7-year average; not included in 1939.

In some localities the land is bedded before planting. At the time of planting, the bed is opened with a small shovel or bull-tongue scooter large enough to clean the beds and deep enough to level the top.

After planting, the row should be slightly below or about even with the middle and with a slight ridge in between. If the land is freshly broken, usually no bed is formed. In this case, planting is made in a small open furrow and the seed are covered sufficiently to level the surface of the furrow slightly below the middle surface. Planting preparation in any case should leave the ground in proper shape for the use of weeders or rotary hoes, or for barring-off rows.

Spacing of Peanuts

Spacing tests to determine distances between rows and spacing of hills in the row have been conducted by most of the experiment stations

Table 6.—Average Yields of Runner Peanuts Spaced at Different Distances in the Row, Wiregrass Substation, Headland, Alabama, 1936-1943[a]

Spacing		*Average yields per acre*
Between rows	*Between hills*	
Inches	*Inches*	*Pounds*
42	7	1,666
42	14	1,594
42	21	1,377
42	28	1,326

[a] 400 pounds per acre 0-8-4 used before planting; 200 pounds per acre of gypsum applied as a top dressing when blooming began.

in the peanut-growing States. These tests have been made with both bunch- and runner-type peanuts. In general, the results show that narrow rows and thick spacing in the row produces the largest yields. When plants are spaced wide in the drill some of the larger types of peanuts produce nuts that are known as Jumbos.

Alabama Agricultural Experiment Station Results. Reported in table 6 are average yields from a spacing test of runner peanuts conducted for 8 years, 1936-1943, at the Wiregrass Substation, Headland. Highest yields were obtained from plants spaced 7 inches apart in the row.

From an experiment conducted at Auburn, Alabama, 1918-1922, inclusive, Funchess and Tisdale (5) found that Spanish peanuts must be planted thick for large yields. They obtained extreme yields of 1,785 pounds of nuts per acre from 4-inch spacing in 18-inch rows and 813

pounds from 12-inch hills in 36-inch rows. Average results for the 5-year period of the test are given in table 7.

Arkansas Agricultural Experiment Station Results. McClelland (10) reported that tests with rows as narrow as 12 to 18 inches apart were conducted in 1919. However, these tests were not continued because of the difficulties encountered in cultivating these narrow rows. The yields of peanuts and of hay were larger than when the peanuts were planted in wider rows.

Table 7.—Average Yields of Spanish Peanuts when Planted at Different Spacings, Main Station, Auburn, Alabama, 1918-1922

Row width	*Spacing in rows*	*Average yield nuts per acre*
Inches	*Inches*	*Pounds*
18	4	1,785
24	4	1,581
30	4	1,308
36	4	1,299
18	8	1,323
24	8	1,170
30	8	1,146
36	8	813
18	12	1,437
24	12	1,158
30	12	1,002
36	12	813

Spacing experiments conducted during the period 1925-1930, inclusive, also were reported. The average results are given in table 8. Spanish and Valencia varieties were used in these tests. Higher yields of both nuts and hay were obtained from the Spanish variety when grown in 30-inch rows and spaced 6, 8 or 9 inches apart in the drill. The Valencia variety produced highest yield in either 30- or 36-inch rows with 6, 8 or 9 inches between the hills.

In a later test (11), 1931-1941, highest yields of the Valencia variety were obtained when spaced 8 inches apart in 30-inch rows. The Spanish strains produced best from a 36-by-8 inch spacing. There was little difference in the yield of either variety between rows of 30 and 36 inches. Spacings of less than 8 inches in the row were not included in the tests. Highest yields of hay from both varieties were obtained from 30-by-8 inch spacing. Average yields of nuts and hay from various spacings for 1931-1934 and for a 9-year average between 1931 and 1941 are given in table 9.

Florida Agricultural Experiment Station Results. In 1928 and 1929

Table 8.—AVERAGE YIELD OF PEANUTS AT DIFFERENT SPACINGS, ARKANSAS AGRICULTURAL EXPERIMENT STATION, FAYETTEVILLE, 1925-1930[a]

Width of rows	*Spacing in row*	*Yields per acre*	
		Peanuts	*Hay*
Inches	*Inches*	*Pounds*	*Pounds*
Spanish			
30	6-8-9	1,190	4,526
30	10-12	1,027	4,151
30	15-16	919	3,197
36	6-8-9	987	3,797
36	10-12	925	3,356
36	15-16	750	2,928
Valencia			
30	6-8-9	525	3,000
30	10-12	509	2,738
30	15-16	371	2,071
36	6-8-9	542	2,708
36	10-12	369	2,170
36	15-16	292	1,771

[a] No results reported in 1927.

Table 9.—AVERAGE ACRE YIELDS OF PEANUTS AND PEANUT HAY, ARKANSAS AGRICULTURAL EXPERIMENT STATION, FAYETTEVILLE, 1931-1934 AND 1937-1941[a].

Variety and Spacings	*Average acre yield 1931-34*		*Average acre yield 1931-1934 and 1937-1941*	
	Nuts	*Hay*	*Nuts*	*Hay*
Inches	*Pounds*	*Tons*	*Pounds*	*Tons*
Valencia[b]				
36 x 8	1,494	2.34	1,316	2.03
36 x 12	1,442	2.25	1,249	1.98
36 x 16	1,284	2.08	—	—
30 x 8	1,394	2.58	1,395	2.25
30 x 12	1,286	2.54	1,260	2.19
30 x 16	1,230	2.28	—	—
White Spanish[c]				
36 x 8	2,520	2.98	2,160	2.60
36 x 12	2,412	2.98	1,873	2.39
36 x 16	2,277	2.94	—	—
30 x 8	2,425	3.20	2,101	2.75
30 x 12	2,331	3.17	2,037	2.69
30 x 16	2,213	3.31	—	—

[a] Crop failures in 1935 and 1936 not included.
[b] Tennessee Red substituted for Valencia in 1941.
[c] Improved Spanish used in tests, 1937-1940.

Table 10.—AVERAGE YIELDS OF FLORIDA RUNNER AND SPANISH PEANUTS SPACED AT DIFFERENT DISTANCES IN 30-INCH ROWS ON NORFOLK SAND, EXPERIMENT STATION FARM, GAINESVILLE, FLORIDA, 1928-1929

Variety	*Spacing of plants in drill*	*Yield of nuts per acre; average 1928 and 1929*
	Pounds	*Pounds*
Florida Runner	6	1,282
	12	958
	24	912
Spanish	3	990
	6	776
	9	631

the station (7) conducted spacing tests with both runner and Spanish peanuts. The average results for the 2 years are reported in table 10. Highest yields were obtained from runners spaced 6 inches and Spanish spaced 3 inches in the drill.

Georgia Coastal Plain Station Results. Average results of spacing tests conducted 1930-1936 (14) are reported in table 11. The tests with Spanish peanuts were conducted at Tifton. Highest yields were obtained from 6-inch hills with rows 18 inches apart. It is reported, however, that this width row is harder to cultivate than wider rows and attention is called to the fact that such narrow rows and spacing require larger quantities of seed. Rows spaced 24 to 30 inches apart with hills 6 inches apart are believed to be the most practical for the Spanish variety.

Table 11.—AVERAGE YIELDS OF SPANISH PEANUTS IN SPACING TEST AT THE GEORGIA COASTAL PLAIN EXPERIMENT STATION, TIFTON, 1930-1936

Spacing		*Yield of unshelled nuts per acre*
Between row	*In row*	
Inches	*Inches*	*Pounds*
36	3	1,393
36	6	1,360
36	12	1,212
36	18	1,131
36	24	932
6	6	1,509
18	6	1,561
24	6	1,503
30	6	1,356
36	6	1,139

North Carolina Agricultural Experiment Station Results. The results from spacing tests with various varieties of peanuts conducted at the Rocky Mount Station (6) are reported in tables 12 to 15, inclusive. Data were obtained on both Virginia Bunch and Jumbo Runner peanuts planted in 3-foot rows in hills 4, 8, 12 and 16 inches apart with one and two plants per hill. Highest yields were obtained from 1929-1931 (table 12) where the Virginia Bunch variety was spaced 4 inches apart in the

Table 12.—Results of Peanut-Spacing Tests, Upper Coastal Plain Station, Rocky Mount, North Carolina, 1929-1931

Distance between hills[a]	Plants per hill	Average yield per acre	Hand picks		Average U. S. grade and class	Total shelling percent	Yield per acre			
			Jumbo	Total			Jumbo hand picks	Total hand picks	Large kernels	Total large and medium kernels
Inches	Number	Pounds	Percent	Percent		Percent	Pounds	Pounds	Pounds	Pounds
					Virginia Bunch					
4	1	1,428	11.2	31.5	5A	65.5	150	450	217	846
8	1	1,227	15.1	42.2	4B	63.1	168	522	214	706
12	1	1,163	15.2	39.3	5B	61.5	159	451	152	619
16	1	1,114	14.4	36.1	5B	61.9	150	400	149	598
8	2	1,390	15.4	40.1	4B	62.9	204	555	234	791
12	2	1,324	16.4	39.5	5B	62.2	206	526	184	734
16	2	1,248	14.8	38.2	5B	61.7	173	480	185	688
					Jumbo Runner					
4	1	1,695	29.9	46.5	2B	63.0	487	815	333	998
8	1	1,700	32.3	49.4	2B	62.3	530	858	282	988
12	1	1,793	36.4	53.6	1B	61.8	621	986	351	1,007
16	1	1,610	38.8	55.5	1B	64.0	601	923	310	954
8	2	1,832	36.2	49.4	1B	61.5	633	901	353	1,016
12	2	1,902	32.3	53.0	2B	63.5	593	1,053	369	1,144
16	2	1,848	32.7	51.3	2B	64.4	597	1,011	368	1,138

[a] Rows 3 feet apart.

drill with one plant per hill. Two plants per hill with hills either 8 inches or 12 inches apart produced only slightly less peanuts than the 4-inch spacing of this variety. Jumbo Runners produced highest yields when spaced 12 inches apart in the drill with two plants per hill.

In other tests conducted in 1929-1931 and 1936-37 at the same location (table 13), approximately equal results were obtained from spacings of two plants per hill 8 inches apart, one plant per hill 4 inches apart, and two plants per hill spaced 12 inches apart. Wider spacing gave much lower yields.

Table 13.—RESULTS OF PEANUT SPACING TESTS, UPPER COASTAL PLAIN STATION, ROCKY MOUNT, NORTH CAROLINA[a]

Distance between Hills	Plant per Hill	Yield per Acre	Grade and Class	Unshelled nuts: Jumbo	Unshelled nuts: Fancy	Unshelled nuts: Total Hand-picks	Shelled nuts: Large	Shelled nuts: Medium	Shelled nuts: Total large and medium	Total Shelling Percentage
Inches	Number	Pounds		Percent	Percent	Percent	Percent	Percent	Percent	Percent
4	1	1,544	3B	18.4	24.7	43.1	14.0	44.6	58.6	64.1
8	1	1,389	3B	20.0	31.1	51.1	16.1	40.5	56.6	61.4
12	1	1,311	3B	20.9	30.6	51.5	13.3	40.6	53.9	60.4
16	1	1,206	2C	22.7	27.7	50.4	13.0	40.3	53.3	59.6
8	2	1,583	3B	19.5	29.1	48.6	14.9	41.3	56.2	60.9
12	2	1,532	2B	23.7	28.2	51.9	14.0	41.6	55.6	61.0
16	2	1,430	2B	21.8	27.1	48.9	14.7	40.4	55.1	60.5

[a] Conducted during seasons of 1929-1931 and 1936-1937.

In tests at Rocky Mount in 1943 and 1944 (table 14) best yields were produced from thick spacing of both North Carolina 31 and Spanish 2B varieties. Both varieties yielded most when spaced 4 inches apart in the row with rows 18 inches wide. In a test conducted in 1947 (table 15), the highest yields from no potash were obtained from hills 4.5 inches apart in rows 18 inches wide. In the case of the potash treatment spacing 4.5 and 9 inches between hills in 18-inch rows and 4.5 inches between hills in 27-inch rows produced approximately the same yields.

South Carolina Agricultural Experiment Station Results. Spacing-test results at the Pee Dee Station, Florence (3) showed that the highest yields were produced where Spanish peanuts were spaced very close in the row, the best yields of nuts being obtained from plants spaced 3 inches apart in 2.5-foot rows. Table 16 records the average results obtained from nuts and forage.

Table 14.—AVERAGE YIELDS OF PEANUTS AT DIFFERENT SPACINGS IN TESTS AT UPPER COASTAL PLAIN STATION, ROCKY MOUNT, NORTH CAROLINA, 1943 AND 1944

Distance between Hills	Average yields per acre, variety and row width: North Carolina 31				Spanish 2B			
	18″	24″	30″	36″	18″	24″	30″	36″
Inches	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
4	1,974	1,876	1,470	1,358	1,862	1,610	1,106	1,330
8	1,732	1,616	1,377	1,435	1,519	1,439	1,175	1,320
12	1,503	1,506	1,280	1,160	1,339	1,328	1,213	1,093
16	1,353	1,351	1,288	1,069	1,162	920	924	998

Table 15.—Results of Peanut Spacing Tests, Upper Coastal Plain Station, Rocky Mount, North Carolina, 1947

Distance between Hills	Average yields per acre from different spacings with and without potash					
	No potash			With potash		
	18 in.	27 in.	36 in.	18 in.	27 in.	36 in.
Inches	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
4.5	2,805	• 2,305	1,557	2,985	3,040	2,305
9.0	2,399	2,218	1,558	3,135	2,506	1,745
13.5	2,311	2,205	1,481	2,910	2,495	1,943

L. S. D. (05) Potash-levels, 196 pounds; row width, 306 pounds; row spacings, 189 pounds.

Texas Agricultural Experiment Station Results. Spacing tests with peanuts have been reported from several Texas substations. At Substation No. 11, Nacogdoches (12), Spanish peanuts were planted for normal stand in 18- and 36-inch rows, 1914-1916. The average yields for the 3-year period were 30 bushels of nuts and 0.59 tons of hay per acre in the 36-inch rows and 32 bushels of nuts and 0.54 tons of hay per acre in the 18-inch rows.

Average yields from experiments at Substation No. 8, Lubbock (12), conducted 1919-1923 and 1925, are given in table 17. Spanish peanuts were used in these tests. Highest yields of both nuts and forage were obtained from the 6-inch spacing between hills.

Table 16.—Average Yields of Spanish Peanuts Spaced at Different Intervals, Pee Dee Experiment Station, Florence, South Carolina, 1917-1919[a]

Row width	Spacing in rows	Yield of peanuts per acre	Yield of hay per acre
Feet	Inches	Pounds	Pounds
2½	3	850	2,023
	6	713	2,057
	9	590	1,610
	12	573	1,693
	15	595	1,560
3	3	763	1,830
	6	653	1,657
	9	653	1,700
	12	570	1,607
	15	477	1,420

[a] 800 pounds per acre of 2-8-3 fertilizer used 1917 and 1918; 470 pounds per acre used in 1919. Shelled peanuts used in 1917 and 1918, and unshelled nuts used in 1919.

Table 17.—Average Yields per Acre of Nuts and Forage from Spanish Peanuts Planted on Lake Charles Clay and Clay Loam at Different Spacings, Texas Substation No. 8, Lubbock, Texas, 1919-1923 and 1925[a]

Spacing between plants[b]	*6-year average*	
	Nuts	*Forage*
Inches	*Bushels*	*Tons*
6	49.6	1.78
9	45.4	1.62
12	42.0	1.51
15	39.8	1.20
18	35.1	1.34

[a] No yield shown for 1924.
[b] 36-inch rows.

Spacing experiments were conducted at Substation No. 3 at Angleton (16). Due to the fact that the spacings of plants in the row were variable from year to year, only the data from 1916-1918 are reported in table 18. The results for other years are in keeping with these data in that the narrow spacings practically always gave the highest yields per acre. Highest yields were obtained from the 6-inch spacing.

Virginia Agricultural Experiment Station Results (2). Recommends spacing Jumbo and Virginia Runner varieties 10 to 16 inches apart in the row with rows 30 to 40 inches apart; and Spanish from 6 to 12 inches apart in the drill with rows 24 to 30 inches apart.

Miller (13) found that increased vine growth was obtained where runner peanuts were dusted to control diseases and insects. Experiments were conducted to determine the spacing between rows that would favor the highest yields of peanuts receiving three or four applications of sulfur dust. It was found that the highest yield of good quality nuts was obtained from dusted plants that were grown in rows farther apart than

Table 18.—Average Yields per Acre of Spanish Peanuts from Different Spacings of Plants, Texas Substation No. 3, Angleton, Texas, 1916-1918

Spacing of plants in row	*Average yield of peanuts*
Inches	*Pounds*
6	2,754
9	2,470
12	2,493
18	2,373
24	1,840

customary. Specific spacing recommendations are not made, but it is suggested that rows be spaced at least 32 to 38 inches apart for runners with plants spaced several inches wider than the customary spacing in the row.

A very large percentage of the spacing experiments with peanuts have been conducted with the Spanish variety. They show that this variety yields most in rows 18 to 24 inches apart with plants 4 to 6 inches apart in the row. Tests in which the larger bunch types or the runner types were used show that they should be planted in 30-inch rows with plants 6 to 8 inches in the row.

Seed per Acre

Poor stands due to planting an insufficient quantity of seed are one of the causes of low yields of peanuts. It is not possible to recommend accurately the quantity of peanuts needed per acre because of the extreme variations found in the size of seed even within a variety. Parham (14) made counts and calculated the approximate seeding rate shown in table 19.

Killinger et al. (7) suggest that 30 to 35 pounds of shelled or 50 pounds of runner seed in the hull are sufficient for planting an acre in 30- to 36-inch rows where peanuts are to be 6 to 8 inches apart in the drill. They suggest 50 pounds of shelled Spanish peanuts for spacings of 3 to 5 inches apart in 24-inch rows.

Sturkie (17) recommends 50 to 75 pounds of shelled seed per acre for

Table 19.—APPROXIMATE QUANTITIES OF PEANUTS NEEDED TO PLANT ONE ACRE AT DIFFERENT SPACINGS

Variety	Hill spacing	Amount of seed needed at five different row widths									
		18-inch row		24-inch row		30-inch row		36-inch row		42-inch row	
		Shelled	Unshelled	Shelled	Unshelled	Shelled	Unshelled	Shelled	Unshelled	Shelled	Unshelled
	Inches	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Spanish	3	89	215	67	161	55	129	45	108	—	—
Spanish	6	45	107	34	81	27	65	22	54	—	—
Spanish	8	34	81	25	61	20	48	17	40	—	—
Spanish	10	27	65	20	48	16	39	13	32	—	—
Spanish	12	22	54	17	40	13	32	11	27	—	—
N.C. Runner	6	—	—	47	118	37	94	31	78	27	67
N.C. Runner	8	—	—	35	88	28	71	23	59	20	50
N.C. Runner	10	—	—	28	71	22	57	19	47	16	40
N.C. Runner	12	—	—	23	59	19	47	16	39	13	34
N.C. Runner	14	—	—	20	50	16	34	13	33	11	29

spacings of 3 to 4 inches in 2-foot rows. In 3-foot rows, 25 to 40 pounds of seed are needed for spacings of 6 to 8 inches between plants.

The Alabama Station conducted 23 tests at eight locations, 1943-1946, inclusive, and obtained practically perfect stands from planting 90 pounds of unshelled Spanish seed. Poor germination, covering either too shallow or too deep, low vitality, and other factors affect emergence and early growth of peanuts. It is usually necessary to plant 20 to 25 percent more peanuts than the theoretical quantity necessary to obtain a stand.

SEED PREPARATION AND TREATMENT

High-yielding strains and varieties of peanuts are being developed. Stock from these improved strains should be obtained by the grower, multiplied and used for planting. When the crop is mature, peanuts for seed should be harvested during dry weather and placed in small stacks around poles as described in another section of this chapter. They should be left in the stack for about 4 to 6 weeks before picking. After picking, the seed peanuts should be either sacked or stored in bulk in a dry place where there is free circulation of air. Peanuts should not be stored in sufficient bulk to cause heating. When they are spread rather than piled in one large heap, there is less danger of heating. Stored peanuts should be protected from mice, rats, insects and other pests.

Shelled vs. Unshelled Seed

Both shelled and unshelled nuts are used for planting. The large-seeded varieties are practically always shelled before planting, but some growers plant the Spanish variety without shelling.

Tests by the Alabama Station show that unshelled Spanish peanuts planted at heavy rates produced good stands and satisfactory yields as compared with an equal quantity of seed that were shelled and planted. Results of these tests are given in table 20. In the tests 90 pounds of seed per acre planted either in the hull or after shelling produced a stand of plants averaging approximately 4 inches between hills. In 14 of the 23 tests, 60 pounds of unshelled seed per acre produced a stand averaging 5.15 inches between hills. It may be seen that unshelled peanuts gave a slightly decreased stand and yield when planted late. These decreases are believed to be due to a shortage of soil moisture at the time of the late planting, which reduced germination of the unshelled seed.

In other tests conducted at Auburn in 1943 and 1944 (19) in which low-vitality Spanish seed were used, low emergence was obtained from un-

Table 20.—AVERAGE NUMBER OF PLANTS PER 100 FEET OF ROW AND AVERAGE YIELD OF SPANISH PEANUTS WHEN PLANTED AT DIFFERENT DATES, USING DIFFERENT RATES AND CONDITIONS OF SEED; VARIOUS LOCATIONS, ALABAMA, 1943-1946[a]

Weight of seed in shell—pounds per acre	*Conditions of seed when planted*	*Average number of plants per 100 feet of row*[b]			
		First planting	*Second planting*	*Third planting*	*Average all dates of planting*
90	Hand shelled	298	351	320	323
90	Unshelled	319	319	277	306
135	Unshelled	422	406	364	397
Average by plantings		346	359	320	342
		Average yield in pounds per acre[c]			
90	Hand shelled	1,406	1,513	1,236	1,385
90	Unshelled	1,473	1,471	1,291	1,412
135	Unshelled	1,425	1,405	1,275	1,368
Average by plantings		1,435	1,463	1,267	1,388

[a] First planting was about the date of the last killing frost and varied from March 9 in extreme southern Alabama to April 17 in northern Alabama. The other plantings were made at 2-week intervals following the first planting.

[b] Average of 23 tests at the eight following locations: Fairhope, Brewton, Headland, Prattville, Auburn, Alexandria, Crossville and Belle Mina.

[c] Yield data from 14 tests at six following locations: Fairhope, Prattville, Auburn, Alexandria, Crossville and Belle Mina.

shelled, hand-shelled and machine-shelled seed. In these tests unshelled seed germinated only 58 percent and hand-shelled seed 72 percent.

In tests by the Georgia Coastal Plain Experiment Station (8), No. 1 hand-shelled Spanish peanut seed germinated better and yielded more nuts than either unshelled or small shriveled seed—often called "pegs." Emergence results from various seed types are presented in table 21.

Table 21.—FIELD EMERGENCE OF SPANISH PEANUT SEED TYPES, GEORGIA COASTAL PLAIN EXPERIMENT STATION, TIFTON, GEORGIA, 1942-1944

Year	*Seed type*				
	No. 1 hand shelled	*No. 1 machine shelled*	*Unshelled*	*Medium pegs*	*Small pegs*
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1942	87	83	64	66	53
1943	76	62	39	51	40
1944	88	82	61	83	78

Method and Time of Shelling

One of the first studies on time of shelling peanuts was by Beattie and others (3). Hand-shelled seed of seven varieties of peanuts—Jumbo, Virginia Bunch, Virginia Runner, African, Valencia, Spanish and Improved Spanish were planted at the Pee Dee Station, Florence, South Carolina, 1922-1924. Shelling was done about February 10, March 10, April 10 and May 10. All seed were planted soon after the last shelling. All peanuts were spaced 6 inches apart in rows 32 inches apart. The data in table 22 show that there was no consistent decrease in the germination of peanuts from seed shelled 3 months before planting time and that shelled shortly before planting. Seed shelled in December and January of 1923 and 1924 also germinated as well as seed shelled immediately before planting.

Table 22.—AVERAGE GERMINATION OF SEVEN VARIETIES OF PEANUTS FROM SEED SHELLED IN DIFFERENT MONTHS, 1922-1924

Variety	Rate of germination[a]			
	February shelling	*March shelling*	*April shelling*	*May shelling*
	Percent	*Percent*	*Percent*	*Percent*
Jumbo	78	82	77	78
Virginia Bunch	87	72	87	79
Virginia Runner	86	75	85	86
Alabama Runner (African)	86	78	79	83
Valencia	89	76	75	87
Spanish	92	87	87	93
Improved Spanish	92	79	81	85

[a] Fractional percentages omitted.

Wilson (19) at the Alabama Station found that hand-shelled runner peanuts gave the same percentage germination whether shelled 6 weeks, 3 weeks or 1 day before planting, and gave practically the same percentage when shelled 9 weeks before planting. Similar results were obtained by the Georgia Coastal Plain Experiment Station (9). Seed shelled in January and planted in April produced stands equally as good as those shelled and planted in April.

Prior to World War II nearly all peanuts for planting were shelled by hand. Some are still hand-shelled, but this method of preparing seed for planting is rapidly decreasing. Labor shortage, labor cost, and the fact that hand shelling is a tedious, monotonous operation account for the decline of handshelling.

Machine shelling often breaks the skin on a large percentage of nuts and sometimes damages the seed by crushing or breaking the nuts in half. This is especially true if ungraded peanuts of uneven sizes are being shelled. It is also true with graded nuts, if the machine is not properly adjusted. When the seed coat is broken, seed-rot fungi have easy access to the kernel and cause decreased germination. Because of the poor stands that have been obtained, machine-shelled seed have often been found unsatisfactory. However, improvement in machines used for shelling, additional experience with their operation, and improved seed disinfectants have resulted in better germination of machine-shelled seed. Relatively small commercial shellers designed especially for handling seed peanuts

Table 23.—EFFECT OF TIME OF SHELLING AND SEED TREATMENT ON THE EMERGENCE OF HAND-SHELLED AND MACHINE-SHELLED RUNNER PEANUTS, MAIN STATION, AUBURN, 1946

Method of shelling	*Seed treatment*	*Percentage of emergence of plants from seed shelled at four different periods prior to planting*			
		Nine weeks	*Six weeks*	*Three weeks*	*One day*
		Percent	*Percent*	*Percent*	*Percent*
Hand........	None	71	80	80	80
Hand........	2 Percent Ceresan	85	86	82	86
Machine.....	None	64	64	51	44
Machine.....	2 Percent Ceresan	80	79	83	80

are now being developed. One such machine known as the U. S. D. A. Peanut Sheller described by Brown and Reed (4) shows much promise for use by relatively small producers. Using medium-vitality peanuts shelled on this machine and treated, Wilson (19) obtained equally good results from hand- and machine-shelled peanuts. These results are reported in table 23.

Seed Treatment

Seed treatment with proper seed disinfectants has been found to improve the germination of both hand-shelled and machine-shelled peanuts for seed. Hand-shelled seed and unshelled seed respond less to seed treatment than do machine-shelled seed. In fact, good stands can often be obtained from planting the recommended quantities from either hand-shelled or unshelled seed without treatment. Treating of hand-shelled seed usually results in 5 to 10 percent increase in emergence. Treatment of machine-shelled seed, however, often increases the stands by 30 to 50

percent. Wilson (19) of the Alabama Station has tested a number of seed-treating materials on Spanish and runner peanut seed. He reported that stands were improved by each of several materials used. However, some of them gave better results than others. He found that the response to seed treatment of Spanish and runners was about the same.

Results at the Alabama Station (table 24) show the effect of various seed disinfectants on emergence of machine-shelled Spanish and runner peanuts over a period of 5 years. Treatments with 2 percent Ceresan and DuBay 1452-F (1½ ounces of the latter to 100 pounds of seed) were two of the best. These results are similar to those obtained at the Georgia Coastal Plain Experiment Station (9) where 2 percent Ceresan, Arasan, Spergon, U. S. R. No. 604 and Dow 9B were found to be of value in the order named. DuBay 1452-F used at the rate of 3 ounces per 100 pounds of seed at the Georgia Coastal Plain Station was toxic to the peanut seed.

Table 24.—Effect of Various Seed Disinfectants upon Emergence of Machine-Shelled Spanish and Runner Peanuts, Main Station, Auburn, Alabama

Disinfectant	*Rate of application per 100 pounds of shelled seed*	*Average number of plants from 100 seeds*	
		Spanish	*Runner*
	Ounces	*Percent*	*Percent*
None	—	48	58
Merc-O-Dust	3	69	67
Dow 9B	3	—	71
Yellow Cuprocide	4	65	73
Spergon	4	66	79
Arasan	3	71	83
Phygon	2	62	80
Ceresan, 2 percent	4	78	87
DuBay 1452-F	1½	86	85

The North Carolina Experiment Station (15) obtained quite satisfactory results from seed treatment of machine-shelled seed. In some cases the percentage of emergence from treated seed has been more than twice that of untreated seed. Some results from seed treatment obtained by the North Carolina Station are reported in table 25. This Station has also conducted tests with Virginia Bunch and Spanish peanuts, in which hand-shelled, machine-shelled and unshelled seed of these two varieties were treated with Arasan. The results of a representative field experiment involving this treatment are given in table 26.

It will be noted that treating machine-shelled peanuts with New

Table 25.—Results of Two Seed Treatment Tests with Machine-Shelled Virginia Bunch Peanuts Conducted in the Field, North Carolina, 1942

Test[a]	*Emergence from seed receiving different treatments*				
	No treatment	*New Improved Ceresan*	*Spergon*	*Arasan*	*Yellow Cuprocide*
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
A	61.2	80.3	92.2	82.5	60.5
B	37.8	75.2	63.3	69.7	69.8
Average	49.5	77.7	77.7	76.1	65.2

[a] The seed used in tests A and B were from different sources. The seed were composed of large and medium sizes

Improved Ceresan, Spergon and Arasan increased the emergence in all cases. However, Yellow Cuprocide was no more effective than no treatment in one test. The Arasan treatment of Virginia Bunch and Spanish peanuts was effective on both hand-shelled and machine-shelled seed. However, there was not much increase in the percentage of emergence from unshelled Spanish variety treated with Arasan.

Results from seed-treatment tests by the Virginia Experiment Station during 1939-1945 showed that the stand of peanuts from machine-

Table 26.—Results of One Representative Field Experiment Conducted to Determine Effects of Seed Treatment on Emergence of Peanuts Shelled by Different Methods, North Carolina, 1942

Variety	*Emergence from seed receiving different treatments*	
	Untreated	*Treated with Arasan*
	Percent	*Percent*
	Hand-shelled	
Virginia Bunch	69.0	76.2
Spanish	68.5	82.6
	Machine-shelled	
Virginia Bunch	39.1	60.7
Spanish	57.5	71.7
	Unshelled	
Virginia Bunch	—	—
Spanish	32.5	39.2

shelled seed can be greatly improved and that the stand from hand-shelled seed is slightly improved by treating with such disinfectants as Ceresan, Arasan, Yellow Cuprocide, Dow 9, and U. S. R. 604. On high-vitality hand-shelled seed, the increase in emergence from treatment is said to average about 5 percent, whereas on seed of low vitality, the increase is proportionately larger. Treatment of high-grade machine-shelled seed, however, increased the stand by 20 to 35 percent. With low-vitality, machine-shelled seed the increase in some cases amounted to many times this percentage. High-vitality machine-shelled seed when treated with a good disinfectant gave about as good a stand as untreated hand-shelled seed of the same lot. Data from which some of these conclusions were drawn are given in tables 27 and 28.

Seed may be shelled and treated during the winter months when labor

Table 27.—Average Number of Plants Obtained from 100 Seed Planted in Seed-Treatment Test, Holland, Virginia, 1943-1944

Treatment per 100 pounds of seed	*Average number of plants from 100 seed*	
	Hand-shelled seed	*Machine-shelled seed*
Arasan, 3 oz.	96	91
Arasan, 2 oz.	94	91
Ceresan, 4 oz.	95	93
Ceresan, 3 oz.	95	95
Yellow Cuprocide, 4 oz.	94	90
Yellow Cuprocide, 2 oz.	93	87
Spergon, 4 oz.	95	85
Spergon, 2 oz.	94	83
Untreated	92	63

Table 28.—Average Number of Plants Obtained from 100 Seed Planted in Seed-Treatment Test, Holland, Virginia, 1945

Treatment per 100 pounds of seed	*Average number of plants from 100 seed*	
	Hand-shelled seed	*Machine-shelled seed*
U. S. R. 604, 2 oz.	91	89
Ceresan, 4 oz.	87	86
Dow 9, 2 oz.	91	87
Yellow Cuprocide, 4 oz.	88	87
Arasan, 3 oz.	90	84
Spergon, 4 oz.	86	84
Fermate, 3 oz.	86	79
Dow 9 B, 2 oz.	85	77
Untreated	84	67

is available. In tests conducted at Auburn (19), seed shelled and treated 9 weeks before planting have produced stands as good as those shelled and treated 1 day before planting. These tests have been in progress for 3 years. In no instance has there been any significant difference in the stands obtained from seeds shelled on the different dates and treated immediately. The results given in table 23 were obtained in 1946; they are in agreement with those obtained in earlier years in other tests.

After the seed are shelled and treated, they should be stored in a dry place. Under such conditions they will keep for several months. Seed shelled, treated and stored in screened cages at Auburn have germinated as well 15 months after shelling as they did at the time they were shelled. Usually, though, it is impractical to carry treated seed over from one year to another because of web-worms that get into seed.

The method used to apply the disinfectant will depend upon the volume of seed to be treated. Whatever method is used, it should insure uniform distribution of the disinfectant over every seed. For best results each seed should be coated with a film of the chemical dust. Some disinfectants will vaporize, and the vapors that enter the sack of seed will kill the disease-producing organisms on the seed. However, such seed will become recontaminated as soon as they are placed in the ground, unless they are covered with a protective coating of the disinfectant. Thorough coverage is especially important on machine-shelled seed to prevent entrance of seed-rotting organisms through breaks in the seed coat.

INOCULATION

Inoculation of peanuts with strains of nitrogen-fixing bacteria has given varied and inconsistent results. Consequently, many stations do not recommend use of artificial inoculation. Apparently, many soils carry the necessary nodule bacteria for this crop. Hence, artificial inoculation rarely has much effect on yield.

Small increases were obtained by the Alabama Station (1) from the use of inoculation the first year that peanuts were grown in localities where the crop was not generally grown. The average results of tests conducted on Norfolk soil at different locations in 1940 and 1941 are given in table 29. The data show that the effect of inoculation on Spanish peanuts was much accentuated by the use of mineral fertilizers applied in the drill before planting. Also, fertilizers were more effective on this soil in the presence of inoculation. It was observed that the plants that grew on the fertilized plots carried substantially more tubercles than the plants on the unfertilized plots.

Table 29.—INFLUENCE OF INOCULATION AND OF FERTILIZERS ON HAY AND NUT YIELDS OF SPANISH PEANUTS, MAIN STATION, AUBURN, ALABAMA, 1940-1941

Fertilizers per acre[a]		*Inoculation*	*Yields per acre*	
			Hay	*Nuts*
	Pounds		*Pounds*	*Pounds*
None		−	1,504	1,102
None		+	1,493	1,117
Superphosphate Muriate of potash	320 50	−	1,408	1,097
Superphosphate Muriate of potash	320 50	+	1,702	1,281

[a] Fertilizers applied in row before planting 70 pounds of shelled nuts per acre.

In other Alabama experiments conducted on the Coosa Valley soils of the Decatur, Etowah and Fullerton series on the Alexandria Experiment Field, peanuts were planted with and without inocculation in 1941. The land used had not grown peanuts prior to that year. Both Spanish and runner were planted on six different areas. The yields of both nuts and hay of each variety were increased by inoculation to the extent of approximately 100 pounds per acre. The results of this test are recorded in table 30.

Most of the chemical treatments used to prevent diseases also kill inoculating bacteria, thus rendering artificial inoculation useless. Albrecht found that Spergon seemed to be an exception to this rule. In tests conducted in 1943 with machine-shelled peanuts, inoculation of Spergon-treated seed produced approximately 14 percent better stands than untreated seed produced approximately 14 percent better stands than un-

Table 30.—AVERAGE YIELDS OF SPANISH AND RUNNER PEANUTS GROWN WITH AND WITHOUT INOCULATION, ALEXANDRIA EXPERIMENT FIELD, ALABAMA, 1941

Treatment	*Yield per acre*			
	Spanish		*Runners*	
	Peanut	*Hay*	*Peanut*	*Hay*
	Pounds	*Pounds*	*Pounds*	*Pounds*
Inoculated	1,321	1,691	1,508	2,970
Uninoculated	1,208	1,552	1,378	2,870
Increase from inoculation	114	139	130	100

inoculated seed treated with Spergon. The per-acre yields in favor of inoculation in the presence of Spergon treatment are:

Spergon-treated, inoculated,	2161 pounds of hay
	1303 pounds of nuts
Spergon-treated, uninoculated,	1825 pounds of hay
	1170 pounds of nuts
Increase from inoculation,	336 pounds of hay
	133 pounds of nuts

CULTIVATION

First cultivation of peanuts consists of running a weeder or rotary hoe in the same direction as the rows. Successive weedings are made with the rows or diagonally across the rows and are continued until the plants are large enough to be broken by such an implement. The practice of broadcast cultivation is very important in producing peanuts with a minimum of hoeing. A weeder may be operated following a rain 2 to 3 days before the soil is sufficiently dry to permit plowing. Thus, weeds may be killed in the seedling stage.

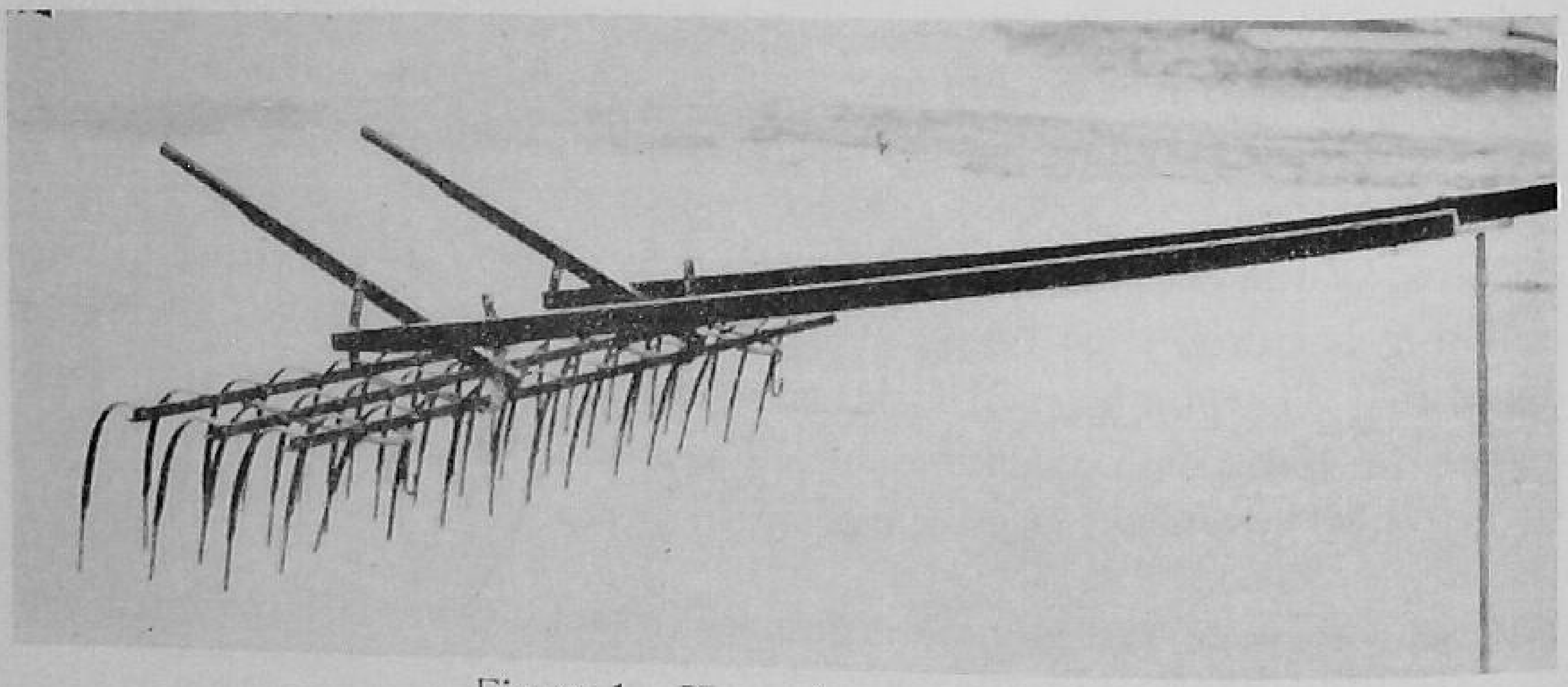

Figure 1.—Horse-drawn weeder.

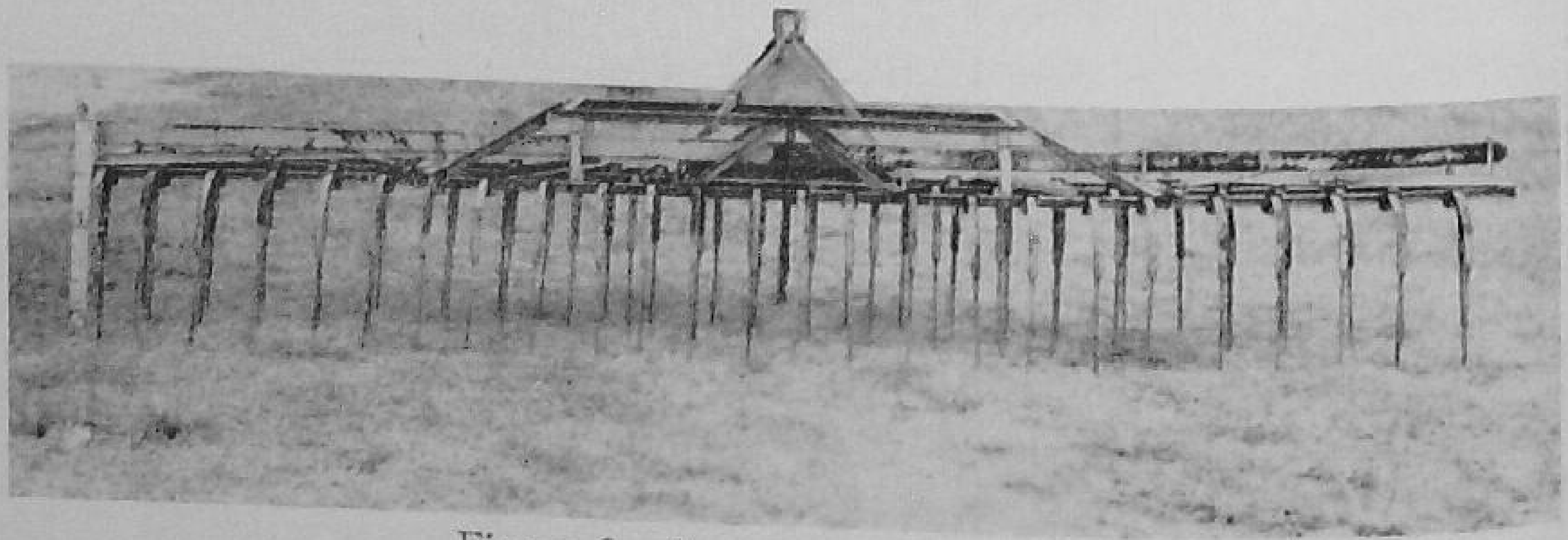

Figure 2.—Tractor-drawn weeder.

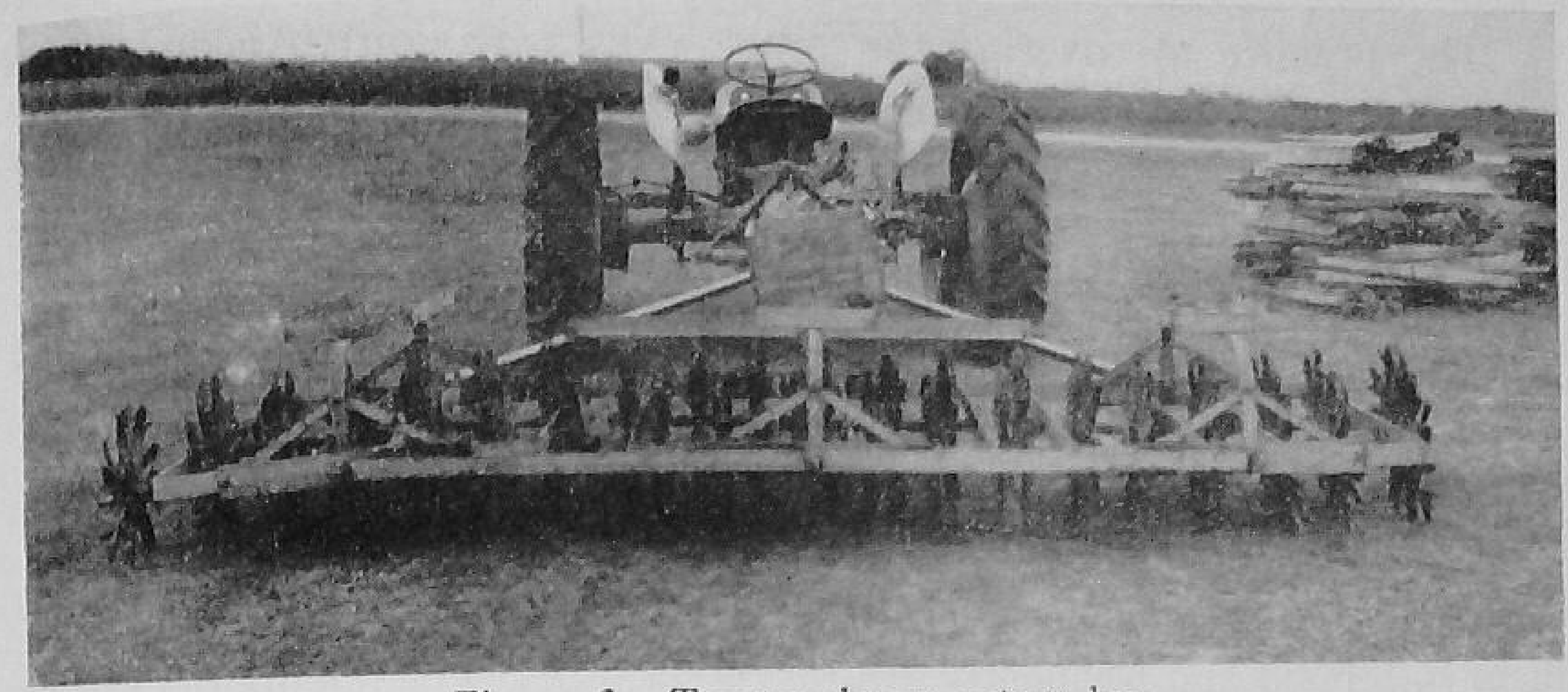

Figure 3.—Tractor-drawn rotary hoe.

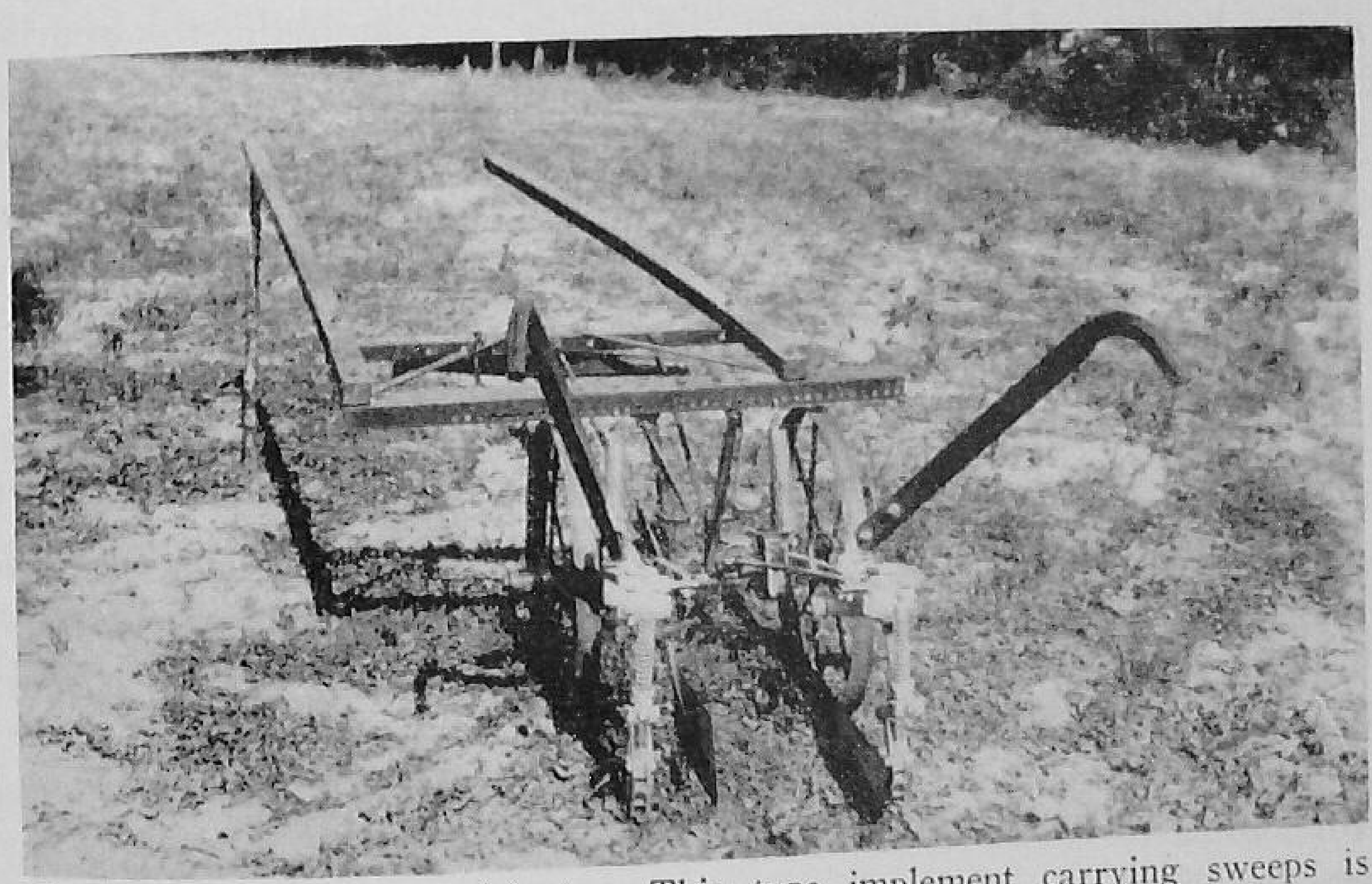

Figure 4.—One-horse cultivator. This type implement carrying sweeps is largely used after the first cultivation.

Later cultivation consists of cultivating shallow with sweeps or other shallow cultivation implements run in the same direction as the rows. Little or no soil is turned toward the plants except at the first cultivation. Pegs (pins or young pods) should never be torn loose. The middle should be kept clean until the vines cover sufficiently to smother weeds.

The principal object in cultivation is to prevent growth of weeds and grass, which are especially harmful because they reduce yield and greatly increase labor in harvesting. In fact, very weedy peanuts are nearly impossible to harvest. Another object of cultivation is to keep the soil loose so that the ovary of the seed stem can pierce the soil readily and thus allow the nuts to form.

The practice of covering the young pegs with soil to insure their pegging down is unnecessary and often is harmful, since it destroys some of the foliage.

Runner peanuts are usually so cultivated as to leave the land flat. Spanish or bunch peanuts are cultivated in such a way as to leave the plants on a bed at the time of laying-by.

Hoeing is necessary in most cases. In favorable years, rapid and frequent cultivation will destroy all weeds and make hoeing unnecessary. If peanuts become weedy or grassy, the weeds or grass should be removed immediately. Removal of weeds or grass after the pods begin to form is difficult and frequently injures the peanuts. The hoeing operation consists of hoeing the plants when small to remove weeds and grass. Another hoeing, which consists of "bunching" or removing the bunches of grass that have been missed during the season, is done at or just before laying-by. The first hoeing operation is quite expensive, usually because less than an acre per day can be hoed by one man. The bunching operation is much less expensive, since one man can cover several acres a day.

Dusting

(Detail of life history and of experiments dealing with control of insects and diseases are discussed in later chapters.)

Two major groups of peanut pests are insects and diseases. Two major insects attacking peanuts are leaf-hoppers and velvet bean caterpillars. The two important diseases that attack peanuts are Cercospora leafspot and Sclerotium, or southern blight.

The use of dusting sulfur, copper sulfur, and combinations of these with compatible insecticides, such as DDT and Toxaphene, are discussed in chapters on insect and disease control.

Spray treatments have been used and various spray schedules have been developed. Use of sprays has been considered impractical for the following reasons:

(1) More time is required to mix and apply the spray than is required to dust.
(2) Costs of spray machinery and materials are higher than the costs of dusters and materials.
(3) There is a greater possibility of burning the foliage by improper use of spray than by dusting.
(4) Frequently, there is not an adequate supply of water available.

Dusted peanuts are usually dug from 1 to 2 weeks later than undusted

plants. The color of the dusted peanut vines is frequently darker than the undusted plants. For this reason, it is very important that the time of digging be determined by examination at maturity of the nuts rather than appearance of the foliage.

Dusting results in larger yields of peanuts and vines, and in better quality nuts and hay.

Machinery

Numerous machines are available for dusting. For large-scale operations, dusting with tractor power take-off equipment is most suitable. In the case of smaller acreages, mule-drawn dusters of the one-horse type are preferable. For only a few acres, hand dusting with the small hand-operated duster is satisfactory. For best results there should be a distributor (duster nozzle) over each row.

HARVESTING

The peanut plant has a fruiting period covering about 2 months. All pods do not ripen at the same time. Thus, it is difficult to tell just when the crop should be dug. If digging is done in time to save the earlier formed pods, then the later ones will be immature. On the other hand, if digging is delayed, many of the early-formed pods of Spanish peanuts will sprout and those of runners and Virginia Bunch are pulled off and left in the soil. The principal object is to dig the crop at a stage when the largest number of mature pods can be saved and when the weather is suitable for curing. If the weather is unsuited for curing, the peanuts cannot be harvested regardless of the stage of growth. Frequently, insects destroy the foliage and make digging immediately necessary in order to save the crop.

The usual method of determining when to dig is to examine the crop frequently as digging time approaches. At intervals of a few days plants should be pulled and the stems and pods carefully examined. If many of the stems have started to decay, digging should be started at once. An examination of the pods will show whether or not the pods are ripe. When a peanut is ripe, the veins of the hulls are prominent and the inside of the hull has turned dark. If the inside of the hull is white, the pod is immature. Another indication of time to dig is that of slight yellowing of the foliage. The leaves become spotted and some of the leaves begin to drop.

A large amount of labor is required for digging peanuts. Therefore, the harvest period usually extends from 2 to 3 weeks. This usually means that

some of the peanuts are dug before the crop is entirely ripe and the last of the crop is dug after the crop is over-ripe.

Usually it is more difficult to determine when to harvest runner peanuts than is the case with Spanish. The runner peanut may set a crop of fruit and if conditions become favorable, a new crop of fruit is set on the ends of the vines. When such a condition occurs, it is necessary to decide whether to harvest in order to save the first crop of fruit or to delay harvest and save the second crop. If the second crop appears to be the larger, it is usually better to delay harvest and save the later crop. The pods that were formed early will be left in the soil, but these can be utilized by hogs, and therefore are not lost.

Figure 5.—Turn plow-type peanut digger.

There are many types of machines used in digging peanuts that work satisfactorily. None of the machines are efficient unless the crop is free of grass and weeds, which clog the implements and make digging difficult. The most common type of implement used in digging bunch-type peanuts is a mold board plow with a long point attached. This cuts the main root and loosens the soil.

For runner peanuts a long flat bar sharpened and attached to a cultivator is used to run underneath the vines. Peanut-digging plows with finger like bars that lift the vines from the soil are in use. Many of the modern diggers are of a 2-row tractor-drawn type.

Another type of digger, somewhat like a potato digger, is coming into use. This implement lifts and shakes the vines, and leaves them on top of the ground—all in one operation. A more recent type of digger, when tractor-drawn, lifts, shakes and puts together two rows at a time, leaving the vines on top of the ground.

After the peanuts are plowed up, they are allowed usually to wilt for 2 to 8 hours before they are stacked. It is customary to windrow the peanuts to facilitate stacking either before or after they are wilted. Windrowing and shaking may be done by hand, by side delivery rakes, or by special machinery. In any case the peanuts should be shaken as free of dirt as pos-

Figure 6.—Bar on two-horse cultivator for plowing up peanuts.

Figure 7.—Tractor with digger blades.

Figure 8.—After windrowing with side-delivery rake peanuts are left to dry.

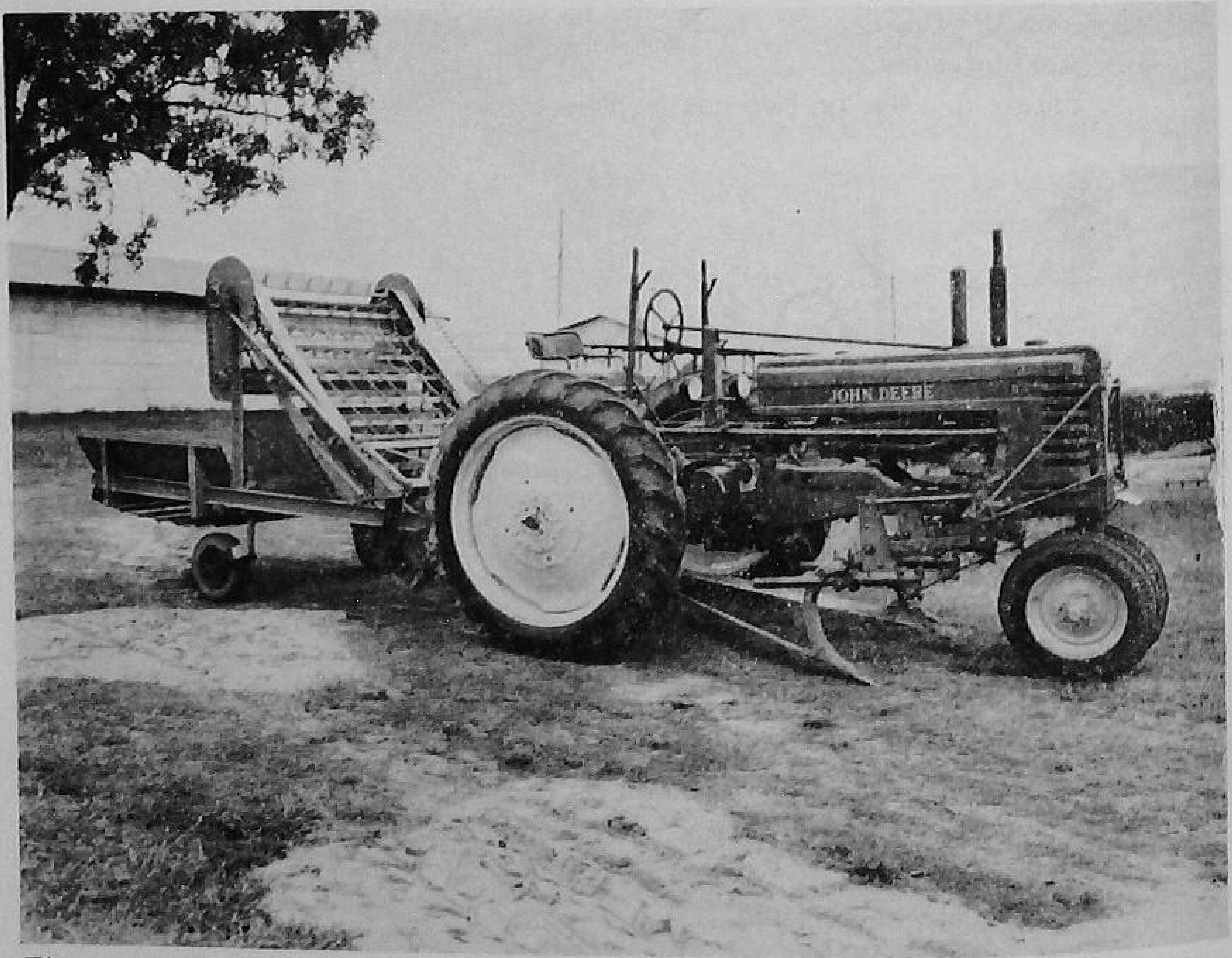

Figure 9.—Tractor equipped with digger blades and mechanical shaker for handling two rows at once.

Figure 10.—Shaking and windrowing peanuts by hand.

Courtesy U. S. Department of Agriculture

Figure 11.—Shaking and windrowing peanuts with side-delivery rake after plowing them up with tractor digger blades.

sible. The windrows may be combined into one large row for about every 10 to 14 rows.

Stacking is usually practiced in most of the peanut belt. It is done as soon as the plants are wilted and before they are dry enough to be brittle. If left on the ground very long, dew and sunlight tend to discolor the pods, and the leaves lose the green color and may shatter, which lowers the hay quality. The vines are stacked around poles, which are firmly placed in the ground so that the stack will not blow over. The poles are usually 2 to 4 inches in diameter and about 8 feet tall. The poles are placed in the ground about 18 inches deep. Greater depth makes it difficult to pull up the poles at picking time. If a shallower depth is used, the poles may blow over. Two slats, about 3 feet long for runners and about 18 inches long for Spanish, are nailed at right angles to the poles 14 to 18 inches above the ground. The slats form two crosspieces on which the first layer of vines is placed. The crosspieces prevent the vines on the bottom of the stack from resting on the ground and allow air to circulate, thus facilitating drying. The center of the stack must be kept open and higher than the edges. The pods of the bunch type of peanuts are placed toward the center. The runner types are usually placed on the poles with pitch forks and no attempt is made to place the nuts so that they are not exposed. Twelve to 14 rows of peanuts are placed in the stack row and a sufficient number of poles are allowed to take care of the stack row. The distance between stacks will depend on the amount of peanuts on the ground and usually will vary from 40 to 50 feet. Successive layers of vines are placed on the stack pole. As the stack nears completion, it is gradually drawn to a point and a few vines are pressed down over the top to complete the stack. A little dry grass frequently is placed on top of the stack to help shed water. In some cases paper or other type of covering is used.

Peanuts are as a rule stacked in the field where the crop is grown, but sometimes the vines are hauled to a central point where the stacks are built close together.

The number of poles required per acre is shown in table 31.

The practice of field curing in the windrow is quite common in the southwestern producing areas. In the Southeastern States it is also sometimes used. In some instances, it is modified by putting the vines in small cocks. The practice works fairly well if weather conditions are favorable for curing, but serious damage may occur if there is much rain before the crop is dry enough to pick. When this system is used, there is always a discoloration of the pods and the hay is of little value. In the Virginia and North Carolina area, this system is not used because in those areas

Table 31.—NUMBER OF STACK POLES REQUIRED WITH ROW WIDTHS AND NUMBER OF ROWS PER STACK AS INDICATED; CLACULATED ON BASIS OF 40 FEET BETWEEN POLES

Row width	*Number of rows per stack*				
	7	*10*	*11*	*12*	*14*
	Poles per acre	*Poles per acre*	*Poles per acre*	*Poles per acre*	*Poles per acre*
	Spanish and Improved White Spanish				
24 inches.	—	54	50	45	39
27 inches.	—	49	45	40	35
30 inches.	—	44	40	36	31
	Virginia Bunch Type				
33 inches.	57	39	—	—	—
36 inches.	52	36	—	—	—

there is little demand for peanuts with even slightly damaged kernels.

More recently experiments have been conducted in picking the peanuts green and drying them artificially. Machines for digging and picking are available. The practice is not yet common and there are not enough available data to indicate how economical it may be. This method offers a possibility of reducing the amount of labor involved in harvesting

Figure 12.—Stack pole properly set for stacking runner peanuts.

Figure 13.—Peanut stack about one-third completed. The stack should be firm throughout with flat top and straight sides until capping is done.

Figure 14.—Completed peanut stack. Note heavy capping well above end of stack pole.

peanuts and of standardizing the quality. If it can be done economically and a satisfactory product produced, it will undoubtedly revolutionize peanut growing.

Picking. Peanuts are cured in a period of 4 to 6 weeks in the stack. In windrows this period is reduced to about 2 weeks. The peanuts are properly cured when the stems have become brittle enough to be broken up and blown out, and when the kernels will split open when rolled between the fingers. There are two types of peanut pickers: One with a cylinder similar to a grain thresher and the other a metal mesh with steel

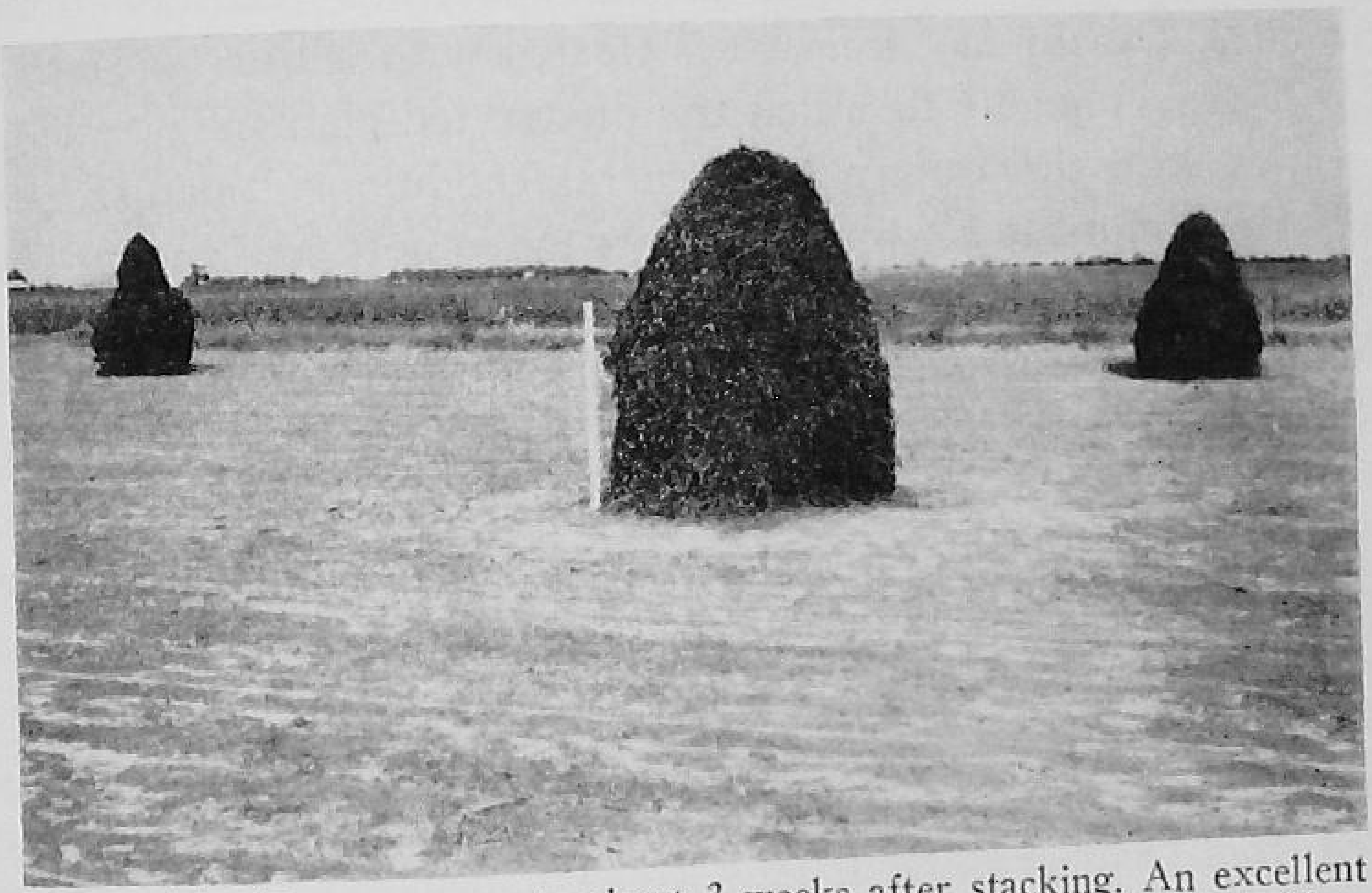

Figure 15.—Runner peanuts about 3 weeks after stacking. An excellent stack in foreground. Fair stack at right, and poor stack at left. Note that bottom of stack has settled away from the capping in the poor stack. This is the usual result of loose stacking.

teeth that tears the vines to pieces but has no cylinder. With either type the peanut vine is thoroughly torn apart and the nuts cut from the stems and vines by a series of revolving saws. The stacks are hauled to the picker behind a specially rigged cart, on flat-bottom wagons, on a "dolly" or sled. In case wagons are used, usually one is being loaded with stacks while another is being unloaded at the picker by feeding the peanuts into the picker.

In operation of the picker, care must be taken not to feed the machine so rapidly that the pods are not cleaned properly. If the machine is operated too fast, many of the nuts are forced out with the hay. The speed of the fans and the picking machinery must be adjusted carefully so as to take care of the particular lot of peanuts being picked.

In many cases peanuts are custom picked and there is a tendency to

rush the job, which results in loss of nuts in the hay and an unnecessary amount of trash is in the nuts. Only dry pods should be picked. Damp weather causes difficulty in picking.

After the peanuts are picked, they should be stored thinly or stirred from time to time until dry. Peanuts should not be stored in bulk until they are fully dry.

Peanut hay is a valuable by-product of the peanut crop. Its quality depends on proper harvesting date and method, and also on proper curing and picking. The hay should be baled immediately after threshing.

Hay left in the field after threshing is exposed to weather and rapidly deteriorates. Usually hay from vines treated with sulfur to control leaf spot is higher in quality than that from untreated plants. The amount of hay varies with the variety and general conditions. Spanish peanuts usually yield from 1 to 1½ tons of hay per ton of nuts, and runner peanuts 1½ to 2 tons per ton of nuts.

Many peanuts are grazed by hogs each year in the Southeastern States. Hogs are used to glean the fields. Frequently peanuts are planted with alternate rows of corn and peanuts are hogged off after the corn is harvested. In many instances peanuts are planted solid for hogging. In most cases the runner-type peanut is used for hogging. The Spanish is earlier than the runner and is used for early hogging, usually from the middle of August to the first of October. Runner peanuts remain in good condition in the ground much longer than Spanish. They are usually hogged from October through January or February. The yield of pork per acre varies with the time of harvesting. Early in the season from 2½ to 3 pounds of peanuts are consumed per pound of pork. As the season advances the pounds of increased growth per pound of peanuts decreases until in February the figure may become as low as from 5 to 6 pounds of peanuts per pound of pork.

Hogs should not be turned on the peanuts until the majority of the nuts are ripe. Hogs do not like immature peanuts and usually will not eat them. Therefore, if the hogs are turned on when the peanuts are too green, they root up many of the vines and waste the immature nuts. Hogs do not like decayed nuts and will not eat them if they can get anything else to eat.

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CHAPTER VII

INSECT PESTS

By

FRANK SELMAN ARANT[1]

The importance of insect damage to peanuts has not been generally recognized, even by the peanut industry and agricultural leaders. Textbooks of economic entomology barely mention peanut insects, although numerous species of pests attack the crop in the field and in storage. These insects feed on the foliage and underground parts of the growing plants, suck the juices of pods curing in the field, and infest peanuts and their products in storage and in transit to markets.

Figure 1. Velvetbean caterpillar and fall armyworm ragging the foliage of peanuts. (The larva nearer the fingers in the picture is the fall armyworm.)

The control of insect pests of peanuts is a serious problem. Scores of species attack peanuts throughout the world, and perhaps a dozen are of major importance in southeastern United States. Information on the control of some of these forms is sparse and in some instances the economic status is controversial. It is the purpose of this chapter to summarize the available information on peanut insects and to point out the need for additional information. Major emphasis is on destructive forms and species of controversial status in southeastern United States.

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Velvetbean Caterpillar

Importance. The velvetbean caterpillar, *Anticarsia gemmatilis* (Hbn.), is a serious pest of peanuts in Alabama, Florida and Georgia, where it appears to be increasing in importance. During the past 10 years some damage from this insect has occurred locally each year, and severe outbreaks over the peanut-growing sections of these States were recorded in 1939, 1944, 1946 and 1948 (65, 52, 6, 7). Prior to this time the insect had been considered of little or no importance on peanuts, although it had received some attention on other crops.

A. gemmatilis damage to velvetbeans in Florida in 1903 was described by Chittenden (28). For several subsequent years, damage from the insect appears to have been observed primarily on velvetbeans. In 1918, Watson (149) reported *A. gemmatilis* attacked peanuts only when the crop was grown adjacent to velvetbeans, and stated that the adults had never been known to oviposit on peanuts under natural conditions. Later Watson (153) reported extensive velvetbean caterpillar damage to peanuts and soybeans. Additional damage to crops has been listed by others (46, 73, 65, 50, 122). Purswell (122) concluded that the insect causes economic damage to peanuts, soybeans, kudzu, alfalfa and velvetbeans, and also attacks cowpeas, string beans, lima beans, sesbania, black locust, horse bean and cotton. Severe damage to crops has been reported from Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina and Texas.

The velvetbean caterpillar feeds upon the leaves of peanuts. Heavy infestations cause complete defoliation of the plants, including destruction of terminal buds. The yield of peanuts is reduced and additional losses result from the shedding of pods in the soil at harvest (52, 6). The yield of hay is also reduced.

Reliable data on losses from velvetbean caterpillar are difficult to obtain. In 1944, the estimated loss in Alabama was placed as high as 10 million dollars, approximately one-third the value of the crop in the State (122). In 1946, the loss in Georgia was estimated at 4 million dollars, and the saving resulting from control at nearly 10 million dollars; in Alabama the loss was estimated at 500 thousand dollars and the saving from control at over 5 million dollars.[2] The extent of control operations in Alabama is indicated by the fact that approximately 4 million pounds of cryolite and 300 thousand pounds of other insecticides were applied in 1946.

[2] Estimate compiled by U. S. Bureau of Entomology and Plant Quarantine.

Description of Stages. Descriptions of the stages and notes on the appearance of velvetbean caterpillar have been published by several writers. The descriptions of immature stages given below are by Watson (148):

Egg

The egg is nearly 2 mm. in diameter and somewhat less in height, and flattened on its lower[3] surface. It is prominently ribbed and white until about a day before hatching, when it turns a delicate pink. . . . The eggs are laid singly, mostly on the underside of the leaves, although many are found on the upper surfaces and some on the petioles and stems.

Larva[4]

First Instar. The newly hatched caterpillar is about 2.5 mm. long and grows to be from 6 to 7 mm. before molting. The head is light brown in color, rounded, bilobed; mouth shining; eyes black. The body is of a uniform light green color without any trace of longitudinal stripes. The tubercles are black and conspicuous; setae also black. The prolegs on abdominal segments 3 and 4 are about equal in size but are much smaller than those on segments 5 and 6 and are not used for walking. A glance at the prolegs is the most ready means of distinguishing the first and second instars. The legs are light brownish yellow.

Second Instar. The markings are now very similar to those of the next instar but are somewhat less pronounced. The most conspicuous longitudinal mark is the black border to the lateral line. The papillae are black as in the first instar, but there is around the base of each a light-colored ring. The first pair of abdominal prolegs, as in the first instar, is less than a fourth as long as the third, weak, and not used in walking or clinging; but the second pair is about half as long as the third. These, too, are ordinarily not used in walking but occasionally are so used.

Third Instar. Head rather square in outline, strongly bilobed, yellowish; ocelli black; mouth dark brown. Body cylindrical; all prolegs used for walking, but the first pair may be somewhat shorter than the others, light yellow; dorsal line pale white, somewhat broken, margined on each side by a darker border. Subdorsal line very pale and indistinct, bordered as dorsal line; lateral line indistinct and broken, narrow, pale white. Substigmatal line wider and continuous but of a paler color than dorsal and subdorsal. Ventral surface yellowish green. Stigmata brown. Tubercles black.

Fourth Instar. Dorsal, subdorsal and sub-stigmatal lines more distinct than in the third instar. All feet used in walking, but the first and to a lesser degree the second pair noticeably shorter than the others. Otherwise this instar is very like the third.

Fifth Instar. Also similar to the third instar, but the longitudinal lines are more clearly defined. Papillae are now white with brown apexes. In the area between the dorsal and subdorsal lines there are a few white dots with a brown border. One of the largest of these is situated near the anterior border and subdorsal line on abdominal segments 1-8. On the metathorax it is double. Stigmatal line is brownish yellow, broken, widely bordered with white on the ventral margin. In the lighter colored individuals this line is often a rich yellow bordered by lines of deep pink.

[3] Surface attached to the leaf.

[4] The description given is of the dark phase. As pointed out by Guyton (65) and others, great variation in color occurs after the first instar. The vigorous manner in which the larva wiggles upon being disturbed is an important distinguishing characteristic in the field.

Sixth Instar. The stigmatal line is colored like the lighter forms of the fifth instar, but the pink is usually replaced by brown.

Pupa

Brown in color, smooth and shining. Abdominal segments punctuated with fine dots which are particularly thick on the anterior half of each segment. Head somewhat pointed. At the end of the abdomen are three pairs of hooked spines, one pair is much larger than the others. Length 18-20 mm., width 4-6 mm. The pupa is light green until it is about a day old.

Adult

No entirely adequate description of the adult has been found. A description based on reports of Chittenden (28), Watson (148), Douglas (46), and observations of the writer follows:

The moth averages approximately 37 mm. across the outstretched wings from tip to tip. The body is stout and narrowed at the apex, measuring approximately 12 mm. from head to tip of abdomen. The color varies from grayish tan to dark reddish brown. Under a hand lens the wings have a peppered appearance, black specks showing on a lighter surface. A line which may be lighter or darker than the rest of the wing extends diagonally across the outstretched wings from near the anterior distal tip of the forewing to the mid-posterior margin of the hind wing. When the wings are at rest this line may appear as the segment of a circle. The part of the wings distal to the line is darker than the proximal part. The wings are bordered with a brown or yellowish line and are heavily fringed with gray or brown. On the under side of the wings is a row of white dots, consisting of 7 dots on each wing. This color pattern is less variable than that on the upper surface. In the field, a character of value in recognition of the moth is its rapid, spasmodic flight. When disturbed it rises quickly, flies rapidly a short distance, and settles suddenly into the foliage of the host plant.

Biology. Life-history studies of the velvetbean caterpillar have been made by numerous authorities (148, 46, 73, 122), but many facts concerning the biology of this species are still unknown. Apparently the insect does not overwinter in the United States except in southern Florida. Watson (148) recorded the presence of adults in southern Florida as early as May 1 and found the northward flight of the moth reached southern Georgia and Alabama by September 1. Subsequently, other investigators have observed the northward migration of moths during the summer months and it has been assumed that overwintering occurs only in southern Florida, Cuba and nearby islands. During recent years, the increasing damage and early appearance of the insect in southern Alabama and Georgia have led to some speculation as to whether the species is becoming acclimated to a more northern habitat. Attempts to carry immature and adult stages overwinter at the Wiregrass Sub-experiment Station in southeastern Alabama have been unsuccessful two successive winters (5). Thus it appears that overwintering does not occur as far north

as the Wiregrass Station, although larvae have been collected in nearby Houston County as early as June 21 (6). The northern limit of the species' overwintering range is not known.

The moth of the velvetbean caterpillar is active principally at night or during twilight. Large numbers in flight may be seen along highways by the light of motor cars. Oviposition also occurs mainly at night or during dark days. Eggs are deposited singly on the underside of the leaves of peanuts and other host plants. Some are also placed on the upper surface and petioles. Rank foliage is preferred for oviposition and there is a tendency to avoid peanut fields where plants are small and foliage sparse,. unless the population of insects is very great.

Development from egg to adult requires approximately 4 to 5 weeks during late summer and early fall. The time has been reported as approximately 30 to 43 days on velvetbeans in Florida (148), 30 to 36 days on soybeans in Louisiana (46) and 32 to 36 days on peanuts in Alabama (122). The egg hatches in 3 to 5 days and the caterpillar feeds 16 to 26 days. Pupation usually occurs in the soil at a depth of one-eighth inch to one and one-half inches. Some larvae pupate on the surface of the ground under litter and occasionally rolled in a leaf, especially on such plants as soybeans and kudzu. The insect remains in the pupa stage 7 to 15 days during warm weather.

Little is known regarding the biology of the adult of the velvetbean caterpillar. As mentioned previously, many of the moths fly northward for many miles and the females then oviposit. The mating habits, preoviposition period, oviposition period, total egg production, and longevity are unknown. Exact information on the distance traveled by moths in flight is lacking as is much other pertinent information on the biology of this pest. It is known, however, that the moth flies much farther north than the insect can overwinter in any stage. All stages perish during the ensuing winter.

Several generations of the velvet-bean caterpillar may occur during a season in Alabama, Georgia, Louisiana and northern Florida. Three distinct generations were reported in 1929 (46) in Louisiana. Four generations were reported in Alabama in 1946 from the middle of June to the first of November (122). Larvae of the second and third generations cause serious damage to peanuts if the initial infestation occurs early and conditions are favorable for the multiplication of the insect.

Additional research is needed on the biology of the velvetbean caterpillar to determine breeding habits, flight, hibernation, host plant relationships, relation of temperature to development and survival, and

factors influencing abundance, such as climatic conditions, diseases, parasites and predators.

Control—Natural enemies and climatic conditions are of value in reducing the population of the velvetbean caterpillar but cannot be depended upon for control. Douglas (46) reported seven species of birds, a predaceous wasp, a hymempterous parasite, and a parasitic fungus attacking the caterpillar. Hinds and Osterberger (73) reported several parasites and predators, including a Tachinid, *Winthemia rufopicta* Bigot, which parasitized as high as 70 percent of the caterpillars. They also described a parasitic fungus identified (46) as *Spicaria prasina* (Maulk.) Saw, considered synonymous with *Botrytis rileyi* observed by Watson (148). Apparently the same fungus, described by Purswell (122), has caused 30 percent fatality to velvetbean caterpillars in fields near Dothan, Alabama. Insect enemies of the velvetbean caterpillar include *Sphex pictipennis* (Walsh), *Solenopsis geminata* (F.), *Calosoma sayi* (Dej.), *C. scrutator* Fabr., *Posidus maculiventris, Proxys punctulatus, Stiretrus anchorago* (Fab.), *Ephialtes aequalis* (Prov.), *Ophion bilineatum* Say, and *Brachymeria ovata* (Say). Dry weather also appears to be detrimental to the multiplication of velvetbean caterpillar.

Insecticidal control of the velvetbean caterpillar on peanuts has been found profitable. Early control practices consisted of applying arsenicals, such as Paris Green, lead arsenate, and calcium arsenate, but considerable burning of foliage resulted on some crops. Douglas (46) found sodium fluosilicate is highly effective and safe on soybeans. Ellisor and Floyd (51) found cryolite to be somewhat less toxic to velvetbean caterpillar than calcium arsenate and acid lead arsenate, but the degree of toxicity indicated the possibilities of cryolite as a control for the insect. Guyton (65) reported the effective use of lead arsenate on peanuts without injury to foliage. Eddy (48) and Bissell and Alden (16) recommended cryolite on peanuts. English (52) found cryolite and 3 percent DDT dusts highly effective. Moderate gains in yield of peanuts resulted from one timely application of these dusts, and where digging was delayed 10 days fewer peanuts were lost in the soil on the dusted plots than on untreated areas. The retention of the pods by the dusted plants at harvest was especially significant and accounted for most of the benefit derived from dusting. Cryolite, DDT, and benzene hexachloride have been reported as highly effective (6). DDT protected peanuts over the longest period; protection given by benzene hexachloride was the shortest. Complete protection from caterpillar damage resulted in gains in yields of 302 to 573 pounds of dry peanuts per acre on land yielding 946

pounds without dusting. The peanuts were harvested before much loss from shedding in the ground had occurred. Loss in the ground was reduced by dusting even after the plants were 90 percent defoliated. Unpublished data (7) indicated effective control of velvetbean caterpillar with cryolite, 10 percent toxaphene, 2 percent DDT, 1 percent gamma BHC, 5 percent methoxychlor, 5 percent DDD, and 1 percent parathion each at the rate of 25 pounds per acre. Five percent chlordane was less effective.

Cryolite at the rate of 20 pounds per acre is the standard recommendation for control of velvetbean caterpillar on peanuts near harvest. It is effective and does not injure the foliage. There is no serious residue problem. DDT is highly effective at rates as low as 0.36 pound technical material (18 pounds 2 percent dust) per acre (161). It is cheaper and faster acting than cryolite. Residue studies, however, have shown that DDT persists on the peanut foliage which is used as hay. The DDT residue on 13 samples of hay collected in Alabama in 1946 varied from 2 to 31 p.p.m., depending upon the interval between dusting and harvest and the rainfall during the period (6). All samples of hay containing less than 7 p.p.m. were from fields on which approximately 6 inches of rain fell over the 4- to 5-week period between dusting and harvest. In practice, peanuts are sometimes harvested within 10 days after dusting. When the DDT-treated hay is fed to livestock, the DDT is stored in the fat and passed in the milk of the animals. Thus, it is ultimately passed on to human beings where it is a possible health hazard, especially to young children consuming large quantities of milk. For these reasons cryolite is generally recommended in preference to DDT for velvetbean caterpillar control on peanuts near harvest.

In 1949, Wilson and Arant reported (160) that four applications of 2.5 percent DDT applied during the summer months for leafhopper control usually control velvetbean caterpillar throughout the season. The last application made approximately 30 days before harvest does not create a serious residue problem. Where dusting is necessary within 30 days of harvest, cryolite or 5 percent methoxychlor is recommended.

Fall Armyworm

Importance. The fall armyworm, *Laphygma frugiperda* (A. & S.), is a periodic pest of peanuts in Alabama, Florida and Georgia. Some damage occurs each season in these States, and not infrequently the insect is present in sufficient numbers to cause complete defoliation of peanuts.

Few references to fall armyworm damage to peanuts are found in

entomological literature. Hinds and Dew (72) reported peanuts as a food of this pest, and Robinson (126) reported serious damage in Barbour County, Alabama. The pest caused severe damage throughout southeastern Alabama and southwestern Georgia in 1948 (6, 7). Control experiments have shown that fall armyworm may reduce the yield of cured peanuts as much as 500 pounds per acre (7, 160).

In addition to feeding on peanuts, the fall armyworm attacks numerous other plants including corn, sorghum, oats and other grasses; alfalfa, soybeans, velvetbeans, cowpeas and other legumes, as well as many other types of plants.

Description of Stages—Detailed descriptions of the life-history stages were made by Luginbill (93). Briefer descriptions have been made by H. G. Dyar and published by Chittenden (27). The descriptions given below of the egg and larva are from Chittenden; those of the pupa and adult are from Luginbill.

Egg

Eggs [deposited] in a close double layer, one above the other, more or less covered with fine gray down from the moth; spherical, well-rounded, the base a little flatter than the apex, uniform; vertical ribs numerous, about 60, small, joined by distinct crossbars nearly as large as the ribs themselves and forming rectangular or slightly hexagonal areas; above, the ribs do not diminish till near the vertex, where they become converted into reticulations, smaller toward the micropyle; color, pearly pink; diameter, 5 mm.

Larva

First Instar. Head rounded, bilobed, about as high as wide, clypeus triangular, half as high as the head, without perceptible paraclypeal pieces; labrum quadrate and with the mandibles projecting; shining jet black; antennae moderate, pale; setae short, pointed; width .25 mm. Cervical shield straight before, rounded behind, jet black, bearing 4 setae on each side; two more (of which one is scarcely visible) detached posteriorly, laterally, prespiracular and subventral tubercles single-haired; anal plate semicircular, dusky blackish. Body whitish, slightly translucent, tubercles large, round, black with very distinct, short, black, pointed setae. Arrangement normal, no subprimaries; on joints 3 and 4, ia and iia small, ib and iib large, all well separated and equally spaced; iv and vi single-haired; on the abdomen i, ii, and iii large, equal, i and ii on joint 12 approximately in a square, iv behind the spiracle and with v as large as the dorsal ones. Leg shields small, quadrate, black; ventral tubercles minute, also black. Feet of joints 7 and 8 slightly smaller than those of joints 9 and 10. After feeding the larva becomes green from the food.

Second Instar. Head round, slightly bilobed, shining black; width .4 mm. Body as before, a little thicker, and joints 12 more distinctly enlarged; cervical shield black; anal plate not cornified, pale like the body, shaded with gray on the sides. Color whitish, with faint traces of dorsal, subdorsal, lateral, and stigmatal lines. Tubercles large, black, and distinct as before, the subprimary ones present. Hairs short, stiff, black. Thoracic feet black, the others pale, with dark shields.

Third Instar. Head round, shining black, the sides covering the eyes and sutures of clypeus, pale luteous; width .65 mm. Shields and tubercles shining black, tubercles large, setae coarse and black. Body greenish gray, dorsal and subdorsal lines whitish, straight, narrow, and even; ground color darker laterally, ending in a blackish shade touching tubercle iv, defined on the ventral side. A broad, pale, substigmatal band; subventer grayish green, shading to the scarcely paler venter. Body uniform, joint 12 very slightly enlarged.

Fourth Instar. Head black, paraclypeal pieces and labrum pale whitish, sides no longer pale, but filled in with black mottlings; rounded, slightly bilobed, shining; width 1.1 mm. Cervical shield black, bisected, not strongly cornified; anal flap dusky; tubercles large, black. Body greenish gray, dorsal, subdorsal (at tubercle ii), and traces of narrow lateral lines pale, as before; substigmatal line broad, white, mottled with greenish and divided by a central band of this color. Feet dusky; setae distinct, black, rather long.

Fifth Instar. Head rounded, slightly bilobed; clypeus large, the paraclypeal pieces nearly attaining the vertex; mandibles prominent; brown-black, sides mottled with pale, especially posteriorly, paraclypeal pieces white, as also the verticle suture; labrum pale, width 1.8 mm. Body cylindrical, normal, joint 12 very slightly enlarged, feet nearly equal. Above dark brown, a little dotted with pale, venter more greenish, but also brown mottled. Dorsal line pale, nearly obsolete except on the thorax and anal plate; subdorsal line distinct, white, straight, a little broken on joints 12 and 13; stigmatal band broad, sharply edged, not inclosing the spiracles, white, nearly filled in with dark red mottlings. Feet all dusky; cervical shield sooty black, not strongly cornified, cut by dorsal and subdorsal lines; anal plate dusky, with two white spots, formed by the broken dorsal line; tubercles distinct, black, with short, stiff, black setae.

Sixth Instar. Head rounded, bilobed, clypeus large, the paraclypeal pieces reaching three-fourths of the distance to the vertex; brown-black, sides posteriorly mottled with pale, sutures white, all as before; width 3 mm. Body as before, joint 12 very slightly enlarged, feet equal. Blackish brown above, varying in shade, the lateral space tending to be darker, as also a space each side of the dorsal line; venter pale greenish, densely mottled. Dorsal line whitish, as broad as the subdorsal and regular, but much fainter; subdorsal line mottled with pinkish, straight. The pale mottlings of the body are heavier between tubercles i and ii and across tubercle iii, suggesting obsolete lines. Slight black streaks bordering the subdorsal line below. Substigmatal band broad, sharp, the edges a little irregular, white, filled in with pale red mottlings. Feet all dusky; cervical shield black, very narrowly cut by white dorsal and subdorsal lines; anal plate dusky, cut by pale dorsal line, with a constriction anteriorly. Tubercles cornified, distinct, dark brown, largest on joints 12 and 13; tubercle iv on joint 5 is opposite the upper corner of the spiracle, on joints 6 and 7 below the middle, on 8 at the middle, on 9 above the middle, on 10 at the upper corner, on 11 low down halfway between the spiracle and tubercle v, and on joint 12 opposite the lower corner of the spiracle. Setae short, rather stiff, dark.

Pupa

Dark reddish brown, darker on the prothorax, black immediately before emergence of the adult; labrum separated from the clypeus by distinct suture, quadrate; fronto-clypeal suture not distinct; libial palpi visible, about one-fourth length of maxillae; mesothoracic wings reaching to caudal end of fourth abdominal segment;

metathoracic wings not visible on the venter, maxillae reaching almost to tip of wings; prothoracic legs over half as long as maxillae, their femora exposed; mesothoracic legs a trifle shorter than maxillae; metathoracic legs showing caudad of maxillae not projecting from caudal margins of wings; antennae a little shorter than mesothoracic legs; sculptured eyepiece somewhat broader than the glazed eyepiece; invaginations of the tentorial arms distinct; vertex narrow on the meson, broader on the sides; mesal length of prothorax one-half that of mesothorax; mesal length of metathorax one-fourth that of mesothorax; cephalic portion of the fifth, sixth, and seventh abdominal segments and the same portion of the fourth abdominal segment on the dorsum finely and densely punctured; area around the spiracles slightly elevated, blackish; caudad of each spiracle is a shallow cavity; spiracles ellipsoidal; mesothoracic spiracle extending over half the length between the antenna and the meson, the area blackish; cremaster consisting of two short, stout, blunt spines; genital opening of female simple; slitlike, apparently situated on the eighth abdominal segment, the cephalic margins of the ninth and tenth segments curving strongly forward toward the genital opening in this sex; genital opening of male simple, slitlike, on the ninth abdominal segment on slight elevation. Length from 14.7 to 17.4 mm. Greatest width 4.5 mm.

Male. Head and thorax ochreous suffused with reddish brown; palpi with blackish patch at side of 2nd joint; frons with blackish bar above; vertex of head suffused with fuscous; tegulae with fuscous patches; pectus whitish; fore coxae and femora suffused with fuscous abdomen ochreous white suffused with reddish brown leaving slight pale segmental lines, the anal tuft tinged with rufous. Fore wing ochreous whitish suffused with fuscous and reddish brown, the inner area paler; subbasal line represented by double oblique dark striae from costa; a black streak below base of cell curved up to cell at extremity; a minute whitish spot defined by black on outer side in cell before the antemedial line, which is indistinctly double, oblique, waved, somewhat bent outwards in submedian fold; claviform represented by a diffused brownish streak, orbicular whitish defined by black and with pale brown centre, a whitish bar beyond it and above base of vein 2; reinform with black and white bar on inner side, its outer edge slightly defined by black and with irregular white marks at upper extremity; a slight white fork at bases of veins of 4, 3; an indistinct oblique waved line from lower angle of cell to inner margin; postmedial line indistinct, double, strongly bent outwards below costa, then minutely waved, incurved at discal fold and below vein 4, some white points beyond it on costa; an oblique diffused whitish shade from apex to vein 6, the whitish subterminal line arising from it, excurved at middle and bent outwards to tornus, some short black streaks before it in the interspaces at middle; a fine white line before termen with series of slight black streaks from it to the black terminal striae; cilia brownish with fine white line at base followed by a dark line.[5] Hind wing semihyaline white, the apex suffused with brown; a dark terminal line from apex to vein 2; the underside with the coastal area slightly irrorated with fuscous, a terminal series of black striae from apex to vein 2.

Genitalia. Uncus represented by a stout, sickle-shaped hook or spine; gnathos about as long as the uncus; harpes large and broad, the anal angles not well defined; marginal spines prominent; claspers hinged at base composed of stout hooks, one on

[5] *Var. fulvosa* (Male).—Fore wing somewhat more suffused with purplish, the white fascia from apex indistinct.

either harpe and attached to it near the anal angle; clavus button-shaped; juxta composed of a chitinized plate in front of aedoeagus attached to articulation of harpes by two stout muscles; ampulla consists of a flap covered with numerous short spines; editum is slender, spiny at tip; peniculus oar-shaped; cornutii composed of 3 groups of several short spines each.

Female. Much more fuscous brown, the costal area and veins irrorated with grey, the lines less distinct; the orbicular and reniform with slight whitish annuli, the former without pale bar beyond it and no white streak at lower angle of cell, the whitish fascia from apex obsolete.

Biology. Adults of the fall armyworm are active during the night and in the late afternoon and early morning. The female deposits eggs in masses on grasses, peanuts or other suitable host plants. The number of eggs per mass is reported (146) as varying from 9 to 349, with an average of 143 eggs per mass. One female lays an average of about 1,000 eggs.

The eggs of the fall armyworm hatch in approximately 3 days and the young larvae feed at first on the surface of the leaves, skeletalizing them. Later they devour the leaves of the plant. The caterpillars feed both in the daytime and at night. Occasionally they may be found hiding under clods at the base of plants, but this habit is not nearly so pronounced as in cutworms. When food becomes scarce, the caterpillars may migrate in large numbers seeking additional food plants. Most crops in the path of the march may be destroyed by this pest. At maturity the caterpillars enter the soil and pupate.

The life cycle, egg to adult, may be completed in approximately 30 days. The winter may be passed in the adult stage in the southern part of the insect's range. Part of the winter may be passed also in the larval stage (146). Apparently, this species is not able to over-winter successfully except in tropical and semi-tropical areas. During the warm months the adults migrate northward and may cause damage by fall in central and northern States.

Control. Natural enemies are important in the control of fall armyworm. Tachinid flies, hymenopterous parasites, and ground beetles are important enemies of the insect. Vickery (146) lists one species of Hymenoptera ovipositing in the egg of the fall armyworm and 8 species in the larvae. Two species of Diptera and one fungus, *Beauveria globulifera*, are also listed as parasites of larvae. The fiery hunter, *Calosoma calidum* (F.), and other ground beetles are listed as important predaceous enemies of fall armyworm (27). The more important insect enemies are as follows: *Chelonus texanus* Cresson, *Apanteles marginiventris* Cresson, *Meteorus laphygmae* Viereck, *Zele melleus* (Cresson), *Sagaritis dubitatus* (Cresson), *Neopristomerus appalachianus*

Viereck, *Ophionbilineatus* Say, *Euplectrus platyhypenae* Howard, *Frontina archippivora* Scudder, *Archytas piliventris* Van der Wulp. Thirteen species of birds and a large number of insects are listed (93) as enemies of the fall armyworm.

Insecticides in the form of dusts, sprays and poison baits have been used in control of fall armyworm on various crops. References to recommended procedures are too numerous to cite. On peanuts, cryolite dust containing approximately 90 percent sodium fluoaluminate has been effective when applied at the rate of 20 pounds per acre. Other materials which have given effective control in Alabama include DDT, toxaphene and parathion (6, 7). A 2.5 percent DDT dust is effective against small larvae but may not kill mature caterpillars. A 5 percent material applied at the rate of 20 pounds per acre is recommended for full-grown caterpillars. Ten percent toxaphene applied at the same rate is also recommended. Two percent parathion is effective but, because of its acute toxicity to warm-blooded animals, it is not recommended for general use by peanut farmers.

Where a combination insecticidal-fungicidal dust containing 2.5 percent DDT is applied at intervals during the summer for leafhopper and leafspot control, fall armyworm is usually controlled satisfactorily on peanuts (160). If weather conditions and timing of applications are such that a population of full-grown caterpillars develops, it may be necessary to apply 5 percent DDT at the rate of 20 to 30 pounds per acre in order to effect control. Ten percent toxaphene and cryolite appear to be slightly more effective against the mature larvae than DDT at concentrations of 5 percent and less. DDT and toxaphene are not recommended on peanut hay within 4 weeks of harvest.

Corn Earworm

Importance. The corn earworm, *Heliothis armigera* (Hbn.), attacks growing peanuts and frequently causes light to moderate damage. Occasionally, severe outbreaks of the insect occur. The writer has observed rather severe damage in 1946 and 1949 over widespread areas in southeastern Alabama. The caterpillars feed on the foliage of peanuts, ragging the plants and in some instances defoliating them. This insect not infrequently occurs in mixed populations with velvetbean caterpillar and fall armyworm. Heavy losses in yield from defoliation or from severe ragging of leaves may occur. Although corn earworm may be considered one of the major pests of peanuts during certain seasons in Alabama, Florida and Georgia, entomological literature contains almost no references

to earworm infestations in peanuts. Merkl (100) lists peanuts as one of the principal crops in Alabama being damaged by this insect but based his conclusion on unpublished records of the Alabama Agricultural Experiment Station. So far as the writer is aware, serious damage has not been reported in the Virginia-Carolina area.

Description of Stages. The various stages of the corn earworm have been described by several investigators. Descriptions given below are taken from the sources indicated.

The egg has been described by Phillips and Barber (113), Quaintance and Brues (124), and others. The description of Quaintance and Brues follows:

Egg

Width, 0.48 mm.; height, 0.50 mm. Shining, waxy white, faintly tinged with yellowish. The form is almost dome-shaped, except that it is slightly narrower at the extreme bottom and widest about the basal third. Base flat and apex obtusely rounded.

The larval and pupal descriptions of Ditman and Cory (45) follow:

Larva

First Instar. Length (soon after hatching), 1.5 mm. Head and thoracic legs, shiny black. Body newly hatched larva very pale and rather transparent; after some feeding, opaque and creamy yellow. There is a very slight tendency to darker and lighter longitudinal stripes, at least in larvae nearly ready to molt the first time. Setae of body of rather medium length, black; on head, some are black and others of a lighter color. Cervical shield and minute setigeral warts dull brownish black; also the prolegs externally, and the anal plate. Around each setigeral wart is a poorly defined circular space of whitish beyond which the generally yellow color of the body appears. The characteristic minute dermal spinules of the older larva are scattered and very indistinct in this instar.

Second Instar. Length, 3.4 mm. Appearance much the same as in first instar. Differs in that the setigeral warts are much broader and show up clearly to the naked eye. The dermal spinulation is more pronounced and general. The longitudinal stripes are but little more evident, if any, than in the previous stage. In the first two or three instars the larvae have a semi-looping gait as do the younger larvae of some of the cutworms.

Third Instar. Length, 7.0 mm. Head, olive brown with darker brown mottlings, especially on each side near vertex; bears a few fine setae. Cervical shield black or slightly brownish, with two short white lateral stripes. Body entirely covered with minute blackish spinules, appearing like a "sand-paper" surface as compared with the skin of most of the related caterpillars. Four narrow white dorsal stripes and a broad white band laterally, alternated with olive brown. Setigeral warts prominent, shiny black, and obtusely cone shaped rather than nearly flat as in previous instars. Setae moderately long and shiny black. Dorsal abdominal warts are larger, especially on first and second segments. Thoracic legs black; prolegs black on their sides both experiorly and on the mesal surface. Crochets black.

Fourth Instar. Length, 11.4 mm. Appearance much as in third instar. Differs in the fact that some of the dorsal stripes laterally now appear broken into short, irregularly disposed lengths interrupted by dark ground color. There is a broader lateral white band in or near which the spiracles lie.

Fifth Instar. Length, 17.9 mm. In general, this stage marks the change to greater contrasts in the markings and to more brilliant colors. The appearance of red hues, as on the ventral surface and in the paler portions of the body markings, is now quite general. Head, orange brown with fine pale setae. Cervical shield and setigeral warts as before, but the latter bearing pale setae. The shield may lose its dark color in many specimens, however. All legs pale; claws of thoracic legs and crochets of prolegs are brownish. Two continuous mid-dorsal white lines now enclose a darker area appearing as a blackish band, in the middle of which lies a third white line. Dorsum laterally to white spiracular band transversed by short white lines on a red and gray ground which becomes darker near the lower edges and tends to concentrate in segmental dark patches in some specimens.

Sixth Instar. Length, 24.8 mm. Appearance much as in the fifth instar, but in general more brightly colored and showing more pronounced individual variation in the nature of the markings. Cervical shield not so dark, and less distinct from the surroundings in many cases, although in some types of larvae it is very distinct.

Pupa

The pupa, just after it is rid of the larval skin, is very soft and delicate and almost larviform. It is pale green on the head and thorax; the wings are transparent with the venation showing as whitish lines; the abdomen is whitish and opaque, with shades of rosy pink dorsally, and orange-colored spiracles. A large transverse rosy spiracle anteriorly bordered with white lies on each side of the prothorax; a transverse median rosy spot between the eye; and four black dots on each eye.

In a half hour after the molt, the pupa has begun to contract and press its appendages into the places habitually taken by them and the pupa. The colors are hidden by the darkening and hardening of the chitinous coat of the pupa. This change to the natural shiny brown of the pupa takes place rather slowly over a period of a day or more. The first portions of the body to darken are the head and dorsal regions of the thorax and abdomen.

Measurements of twenty-two pupae showed that there is comparatively little variation in size in this stage. The length was found to average 19.1 mm., ranging from 17.6 mm. to 20.6 mm. The breadth of the pupa at the widest point across the back or dorsum is a little greater than the greatest depth from the dorsal to the ventral surface. The average measurement in the first cases was 5.5 mm., while the average depth was 5.4 mm.

The original description of the adult (53) was translated by Ditman and Cory (45) as follows:

Adult

A bombyx, with wings deflexed and yellowish; with a middle spot and posterior obsolete streak rather obscure. Habitat, islands of South America. Collector, Father Smith. Of medium size. The antenna simple. The body yellowish with a more obscure middle spot. Posteriorly with an obsolete streak which is spotted with very small

punctures. Hind margins brownish. Hindwings yellowish, with posterior margin fuscous.

Biology. Studies on biology of the corn earworm have been made by numerous workers (81, 112, 13, 45). The insect over-winters in the pupal stage which may be found 2 to 6 inches below the surface of the soil. The adult emerges in the spring or early summer, and the females soon begin depositing eggs. Eggs are laid singly on the leaves and terminal buds of many plants. When corn in the silking stage is present the eggs are deposited on the silks. One female may lay as many as 3,000 eggs. On peanuts, the caterpillars feed on the leaves, causing ragging of the foliage, or even complete defoliation of the plants. When the larva is mature it pupates in the soil. Time required for complete development, egg to adult, is approximately 30 days under favorable conditions.

In addition to feeding on peanuts, this insect is a major pest of several other crops including sweet corn, field corn, cotton, tomatoes, tobacco, soybeans and other plants. It is commonly called corn earworm, tomato fruitworm, or bollworm, depending upon the crop it infests.

The moths are most active at dusk or during warm, cloudy days. They are strong flyers and may migrate for considerable distances before depositing eggs. There appears to be a tendency for the migration to be northward.

Control. The literature available on control of corn earworm is too extensive to review in this paper. Winburn and Painter (162) reported 46 hymenopterous and 22 dipterous insects that aid in natural control. An enormous amount of research has been conducted on the chemical and cultural control of *Heliothis armigera* on corn, cotton, tomatoes and several other crops. However, very little information is available on control of this insect on peanuts. Experiments conducted at the Wiregrass Substation of the Alabama Agricultural Experiment Station have shown that the insect may be successfully controlled on peanuts with cryolite, DDT or toxaphene (5, 7, 8). The insect is most readily controlled when the larvae are small. Full-grown caterpillars are somewhat resistant to most insecticides. Cryolite should be used undiluted at the rate of at least 20 pounds per acre for control of earworms on peanuts. Two and one-half percent DDT dust at the same rate is effective against small larvae. It is not highly effective against mature forms. Where a population of fully grown caterpillars develops before control measures are applied, a dust containing at least 5 percent DDT is required for satisfactory results. Ten percent toxaphene is highly effective against small larvae and moderately so against mature forms.

The recommended practice for control of corn earworm in the Alabama-Florida-Georgia area is applications of 2.5 percent DDT at 7- to 10-day intervals in a regular dusting program for control of insects and diseases (160). Where infestations of last-instar larvae are found 5 percent DDT, 10 percent toxaphene, or cryolite should be used. Infestations which occur within 4 weeks of harvest should be controlled with cryolite if the vines are to be used for hay.

Potato Leafhopper

Importance. The potato leafhopper, *Empoasca fabae* (Harr.) may attack peanuts wherever they are grown commercially in the United States. The related species *Empoasca facialis* Jac. is reported on peanuts in South Africa (107); *E. solana* DeLong occurs on peanuts in Hawaii (76) and *E. flavescens* (F.) on peanuts in Dutch East Indies (89).

In addition to injuring peanuts, *E. fabae* attacks a wide variety of plants including potato, bean, clover, alfalfa, soybean, eggplant, rhubarb, cotton, dahlia, apple and many other plants. Several common names have been used for this insect, each referring to a host plant. It might be

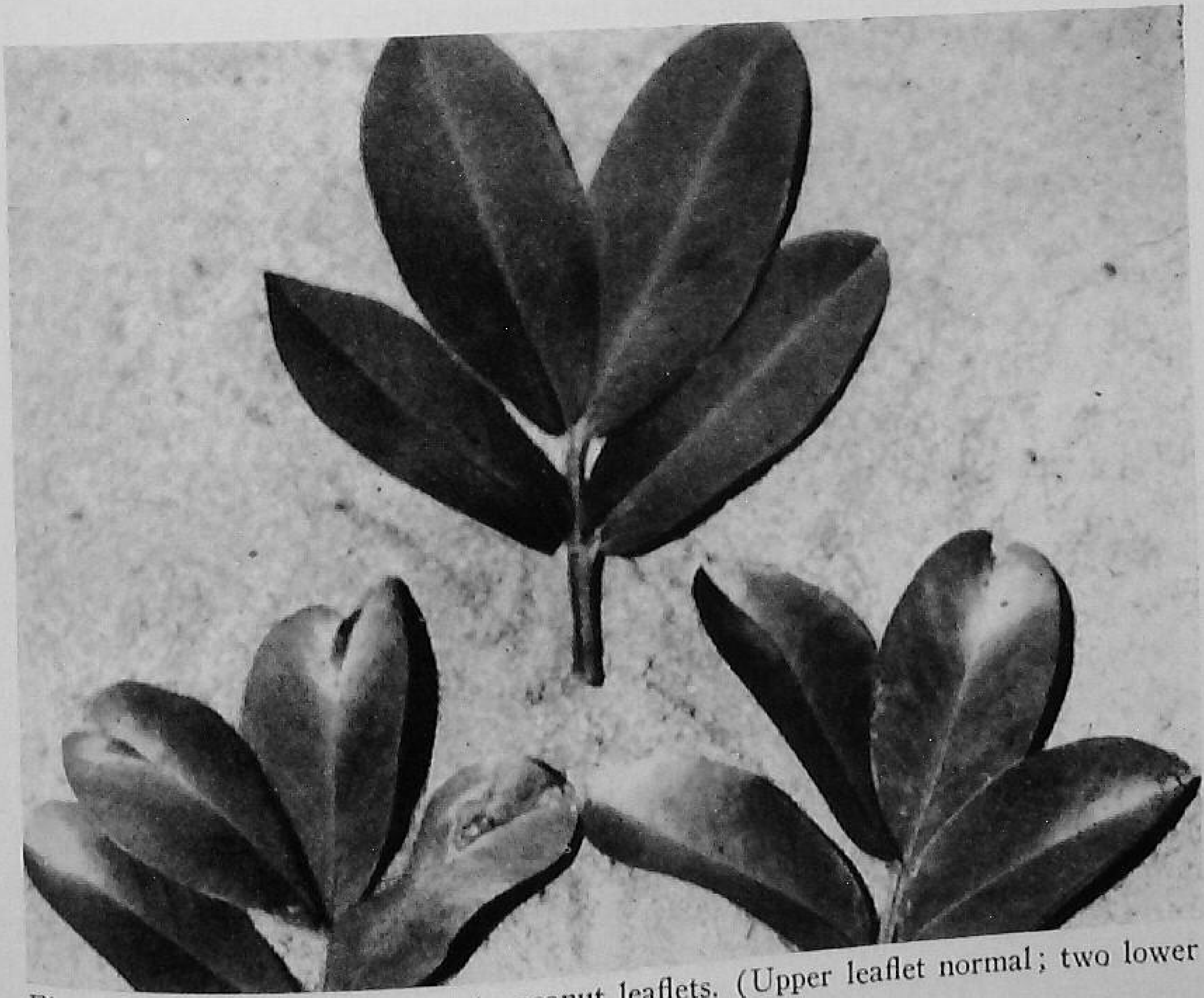

Figure 2. Leafhopper damage to peanut leaflets. (Upper leaflet normal; two lower leaflets damaged.)

called peanut leafhopper, but the official common name is potato leafhopper, a name suggested by Ball (12) to indicate potato as a preferred host.

Both adults and nymphs of the insect feed upon peanuts by sucking juices principally from the lower epidermis and veins of the leaves. Some damage may result also from the deposition of eggs. As a result of leafhopper damage to peanuts, the tips of the leaflets turn yellow and as the damage becomes more acute the yellowing progresses toward the base of the leaflets and some of the tips may appear burned. Damage is more severe during dry weather. A field of infested peanuts may have a yellowish appearance rather than characteristic green. Batten and Poos (14) reported a dwarfing as well as yellowing of foliage in severe infestations in Virginia. Metcalf (102) reported a disease called "pouts" resulting in peanuts from the mass effect of toxins injected by *E. fabae;* the leaflets turned dark at the tips, and the whole leaf sometimes blackened and died. Apparently, this condition was severe "hopperburn"; it should not be confused with a dwarfed condition, also sometimes called "pouts," resulting from thrips damage.

There is considerable evidence that leafhoppers reduce the yield of peanuts (117, 14, 104, 7). In some instances, however, there has been no clear differentiation between the effect of damage from leafhopper and Cercosporo leafspot. There is need for more exact information on losses caused by potato leafhopper to Spanish, runner and jumbo types of peanuts. The losses should be measured in terms of yield of peanuts and yield and quality of hay.

Description of Stages. The potato leafhopper was originally described by Harris in 1841 (66) as *Tettigonia fabae* and the Genus *Empoasca* was established by Walsh in 1864. Subsequently, numerous descriptions have been published under several synonymous names. The descriptions of immature stages given below are from Ackerman and Isely (1); that of the adult is from DeLong (42):

Egg

Egg elongate, subcylindrical, very delicate, slightly curved from end to end, somewhat rounded at both ends, but more so at the anterior end. When first deposited it is rather transparent, but in a few days it changes to a pale yellow while a small white cap forms at the anterior end through which the red eyes of the immature nymph are perceptible. Average length 0.82 mm., width 0.25 mm.

Nymph

First instar. Pale white, changing to a light yellowish green after feeding. Eyes dull red. Small pale spines on the dorsal side of the head, thorax, and abdomen; the latter with four spines to each segment arranged in two longitudinal rows along

each side, one spine situated dorso-laterally, the other ventrolaterally. Posterior margin of metathorax blunt. First two segments of antennae pale, the remainder dusky. Average length 1 mm.

Second instar. General color light yellowish green. Eyes losing some of their red color. Posterior border of metathorax sharp in outline. First two segments of antennae light yellow, remainder dusky. Average length 1.30 mm.

Third instar. General color pale yellowish green. Eyes almost pearl white. Body more robust than in first two stages. Wing pads appearing as lateral buds extending to the hind margin of the first abdominal segment. Spines darker and more prominent. Average length 1.85 mm.

Fourth instar. Head and thorax yellowish green; abdomen yellow. Eyes pearl white. Wing pads extending to hind margin of second abdominal segment. Spines prominent. Average length 2.1 mm.

Fifth instar. Head and thorax pale green; abdomen yellow. Wing pads extending to, or nearly to, the hind margin of the fourth abdominal segment. First two antennal segments green, remainder dusky. Body broader than in previous instar. Average length 2.6 mm.

Adult

Pale green, usually with a row of white spots on anterior margin of pronotum. Length 3.5 mm.

Vertex bluntly angled, a little longer on middle than next to eye and about one-third wider between eyes than length at middle.

Color. Yellowish to pale green, markings variable; vertex frequently with pale or dark-green spots; pronotum usually with a row of six or more pale spots along anterior margin, sometimes missing or indistinct; elytra greenish subhyaline.

Female genitalia. Last ventral segment moderately produced and roundedly truncated.

Male genitalia. Valve produced and rounded or bluntly angled; plates triangularly tapered to pointed apices, which are frequently upturned; lateral processes of the pygofers rounded on inner margins and broadened on apical half, then concavely rounded to narrow attenuated tips, which are slightly curved inward; spines of tenth segment broad, with tips narrowed and directed downward. This combination of characters will distinguish *Empoasca fabae* from closely related species.

Biology. Many studies have been made on the biology of potato leafhopper on potatoes, beans and other crops, but none has been made on peanuts except in the form of general observations. Beyer (15) reported the results of life-history studies of the insect on beans in Florida and Poos (114) reported similar studies on cowpeas in Virginia. There likewise are rather comprehensive reports from other sections on the biology of the insect (54, 1, 41).

The potato leafhopper apparently over-winters only in the Gulf-Coast States where some breeding may occur throughout most of the winter. As the weather becomes warm in the early summer it spreads northward and causes damage to a variety of crops during the summer and fall. Cold weather presumably destroys all stages of the insect except in its south-

ern range, where the winter may be passed on any green host plant such as alfalfa, clovers, castor beans and other plants. Beyer (15) found it throughout the winter on castor beans. It is possible that hibernation may occur, either in the egg or adult stage, in part of the insect's range, but all evidence on hibernation is negative.

The time required for development from egg to adult is 18 to 24 days during warm weather (42, 14). As the weather becomes cool, this period may increase to 60 days. Approximately 5 to 10 days are required for incubation of eggs and 8 to 15 for nymphal development. Females mate and begin ovipositing in 3 to 5 days in the veins and petioles of the leaves. Approximately 60 eggs per female are deposited over a period of 30 days during warm weather. A maximum oviposition of 131 fertile eggs has been reported in Florida (15).

The average longevity of the female is approximately 35 days, although a maximum of 123 days has been reported in Virginia (114). Longevity of males is somewhat shorter. Six generations per year have been reported in Virginia and Florida.

Additional research is needed on potato leafhopper to determine its development on peanuts, overwintering habits, and the relation of development on various wild and cultivated host plants to damage in peanuts.

Control. Natural enemies are apparently of relatively minor value in suppressing the population of potato leafhopper. Heavy rainfall reduces infestation in peanuts. A parasitic fungus, *Entomophthora sphaerosperma* Fresenius, causes a disease which is of considerable importance. The disease has been reported from Florida (15), Arkansas (1), Iowa (54), and other localities. Eighty percent of the insects may be diseased, and as high as 37 percent of those affected may perish. Chrysopid and coccinellid larvae are important insect predators of the potato leafhopper, *Chrysopa plorebunda* Fitch and *Hippodamia 13-punctata* being species commonly observed. The predaceous bug, *Triphleps insidiosus* Say is also a natural enemy as are certain spiders, ants and birds. Insect parasites in potato leafhopper appear to be rare, although *Anagrus armatus* Ashm. is reported common in Iowa.

Numerous studies have been made on insecticidal control of potato leafhopper on potatoes, beans and other crops. Some studies have been made also on peanuts. Poos and Batten (117) found that 4:4:50 Bordeaux mixture applied to peanuts in Virginia increased the yield 21 percent. In 1938 these investigators reported more extensive experiments with sulfur and copper dusts and sprays which resulted in very substantial

increases in yield. Miller (104) reported similar results. In none of these reports was there a clear differentiation between increases from leafhopper and disease control, although leafspot is given as a factor. The same authority (106) has reported the potato leafhopper as the most injurious insect of peanuts in Virginia, and stated that sulfur applied for leaf-spot control repelled and controlled leafhopper, even on undusted areas in small-plot experiments. Poos (116) found that 2 percent DDT reduced the infestation of the insect on peanuts and Poos, Grayson, and Batten (120) reported some increase in yield of peanuts and hay from control of leafhopper, but none of the differences was significant. Non-significant increases were also recorded (5) in yield of sound, shelled peanuts in Alabama in 1947 from the use of DDT sprays and dusts on runners. In 1948b, however, the dusting of Spanish peanuts 4 times for leafhopper control in Alabama resulted in decreased infestation and in average gains in yield as follows: 2 percent DDT, 302 pounds dry peanuts per acre gain; 2 percent DDT in 90-10 sulfur-copper, 468 pounds per acre; 20 percent toxaphene, 470 pounds (7). Two percent gamma BHC and 5 percent chlordane were less effective. Four applications of dust to runner peanuts for leafspot and leafhopper control resulted in average gains in yield as follows: Sulfur-copper, 90-10, 264 pounds of dry peanuts per acre; 2 percent DDT, 339 pounds per acre; sulfur-copper plus 2 percent DDT, 444 pounds. Where 10 dustings were made with DDT throughout the season, no significant gains were recorded. In a non-replicated, preliminary test, 9 dustings with 20 percent toxaphene for thrips and leafhopper control resulted in excellent control of both insects and a 67 percent increase in yield over the check.

Thus it appears that control of potato leafhopper on peanuts is profitable. It also appears feasible to control leafspot and leafhopper in one operation with a combination insecticide-fungicide. Little is known, however, regarding the relative value of controlling the insect on Spanish, runner and Jumbo peanuts. Little is known regarding the value of control on different soils, although observations indicate that damage is more severe on poor than on more fertile soils; presumably more profits might be derived from control on the less fertile soils.

A combination insecticidal-fungicidal dust has been recommended (160) for control of leafhopper and leafspot in one operation. The dust mixture recommended contains 2.5 percent DDT, 3.4 percent copper, and at least 65 percent sulfur. Four to 5 applications of the dust are applied at approximately 10-day intervals. The last dusting should be 4 weeks before harvest, if the peanut vines are to be used as hay. The DDT-sulfur-

copper dust is recommended for peanuts in the Alabama-Florida-Georgia area.

A dust containing 1 percent DDT and 90 percent sulfur has been recommended (119) for dusting peanuts in the Virginia-Carolina area. Three applications are recommended at 3-week intervals, beginning July 10 to 15.

Tobacco Thrips

Importance. Thrips damage to young peanuts is widespread over most of the peanut-producing areas. The tobacco thrips, *Frankliniella fusca* (*Hinds*), is the principal species involved, although the flower thrips, *F. tritici* (Fitch), also infests peanuts, living mainly in the flowers (120). *Heliothrips indicus* occurs on peanuts in Sudan (32). *Taeniothrips distalis* Ky. and *T. longistylus* Ky. are reported damaging peanuts in India (125).

Apparently, the first thrips injury to peanuts in the United States was observed by Watson (149) when he collected *F. fusca* from this crop. In 1922 he reported widespread damage in Florida during the spring of 1919. Since that time the insect has been observed throughout most of the peanut-growing section of the country. In addition to peanuts, *F. fusca*

Figure 3. Leaflets of peanuts showing typical thrips damage.

attack tobacco, cotton, beans, peas, Irish potato, oats, cocklebur, dewberry, evening primrose, crab grass, tomato, vetch and many other plants (77, 49).

Thrips attack peanut plants most severely while they are small. The upper surface of the developing leaflets are rasped by the insects and as the leaflets unfold they have a scarred and even deformed appearance. Farmers often refer to damaged peanuts as "possum-eared," a term quite suggestive of the appearance of the leaflets. The plants fail to grow properly. Where infestations are severe, stunting occurs and the damaged peanuts recover slowly and perhaps incompletely. Thrips damage usually disappears or becomes less acute, concurrently with increased rate of growth of the plants, the more rapid growth probably resulting from the nitrogen fixation and favorable climatic conditions.

Thrips injury has been referred to as "pouts." The peanuts, in farmer language, were said to pout until blooming time when growth became more rapid (115). Another condition caused by potato leafhopper has also been called "pouts." It is apparent that the term "pouts" is not specific, and should not be used to designate thrips injury (133).

It has been assumed by many that peanuts grow out of the stunted condition resulting from thrips infestation and little permanent harm results. Recent studies discount this view. As a result of experiments at Beltsville, Maryland, it was concluded (116) that thrips reduced the yield of peanuts as much as 37 percent. Substantial increases in yields were reported, in some instances, from control of thrips in Maryland and Virginia (120). The author (7) found that control of thrips on runner peanuts resulted in the setting of fruit earlier than on undusted plants, although most of the early crop was lost in the ground at harvest. It appears that permanent damage may result from thrips infestation resulting in decreased yield of peanuts.

The degree of damage doubtless varies with the type of peanuts, fertility of the soil, and weather conditions as well as with the insect infestation. Apparently, damage is more severe and recovery slower on poor than on fertile soils. Additional research is needed to clarify these points.

Description of stages. Two forms of *F. fusca* adults occur (49), one with shorter wings than the other. The relative length of wings varies also with the distention of the abdomen at the time of measuring. It is not clear from the literature whether the original description of the insect (69) was of the short- or long-winged type. In 1905, however, the insect was described (70) under the name *Euthrips nicotiannae* from long-winged females. These descriptions are given below:

Egg

The eggs are deposited in the tissues of the stem and leaves.

Larva, first stage

Length about 0.23 mm.; width of mesothorax 0.11 mm. General shape fusiform. Color of posterior part of thorax and entire abdomen pale yellow; elsewhere pearly white. Head quadrate; eyes reddish. Antennae 0.15 mm. in length; distinctly four-segmented; basal segment cylindrical, short; second ovate, slightly shorter than the third; third slightly conical, the apex joining the second; fourth fusiform, widest near the basal fourth, about equal in length to the other three. The fourth segment is distinctly annulated, the second and third indistinctly so; setae are present on all segments, most numerous on the fourth. Legs translucent white, stout. Abdomen tapering posteriorly; with ten segments, the first eight nearly equal in length, the ninth twice and tenth three times the length of the preceding. Each abdominal segment with longitudinal rows of setae, the ninth with two and tenth with four spines that are four times the length of the setae.

Larva, second stage

Length from 0.6 to 1.17 mm.; width of mesothorax from 0.14 to 0.2 mm.; shape same as in first stage. Color of thorax and abdomen yellowish, with exception of the last abdominal segment. Head quadrate; antennae with four segments, the fourth being more distinctly annulated than in the first stage. Abdomen with the setae increasing in length posteriorly; ninth and tenth segments about equal in length, each less than twice the length of the others.

The young nymph or prepupa

Length, 0.52 to 0.62 mm.; width of mesothorax, 0.10 to 0.12 mm. Antennae translucent, extending forward, much shortened and composed of five segments, first two cylindrical and very short, third and fourth globose, fifth tapering to the apex. The last segment of the abdomen is set with four spines by use of which the young nymph seems to protect itself, when approached by another the abdomen being turned upon it. The wing sheaths are very noticeably separated, the upper one extending to the middle of the second segment, the lower one to the middle of the third segment. The legs are translucent white, stout.

The full-grown nymph or pupa

Length, 0.68 to 1.22 mm.; width of mesothorax, 0.15 to 0.20 mm. Shape similar to the adult. Color yellowish; head, antennae, wing pads, legs, and caudal segments of the abdomen varying to pearly white. Antennae extending to the middle of the prothorax. Three yellowish ocelli between the eyes, the latter dark red. Wing pads so closely applied as to appear single, extending to the middle of the fifth abdominal segment; length from head to tip of wing pads 0.39 mm. The abdomen is noticeably contracted longitudinally; greatest width, 0.24 mm.; longest setae, 0.078 mm.

Adult

Average length, 1.05 mm. (0.95 to 1.13 mm.); average breadth at middle of abdomen, 0.27 mm. (0.225 to 0.285 mm.). General color of head and thorax light brown or tawny yellowish-brown; abdomen dark brown.

Head about one and one-half times as wide as long, frequently slightly retracted under anterior margin of prothorax; occiput transversely wrinkled, posterior margin strongly thickened and darker in color; anterior margin slightly bisinuate, cheeks

approximately straight and parallel. Eyes dark red in color, not protruding, occupying together fully one-half the width of the front of the head and being one half as long as the head; margins around eyes pale yellow in color; surface of eyes finely faceted and slightly pilose; three ocelli present, well separated, posterior ones contiguous with yellow borders to eyes, pale yellow in color and margined inwardly with pale-orange crescents; one moderately stout dark spine in front of each posterior ocellus; postocular spines weak and inconspicuous. Mouth cone reaching nearly to posterior edge of the prosternum, tapering abruptly; maxillary palpi slender, three-segmented. Antennae inserted slightly below front margin, approximate at base, about two and one-half times as long as the head and approximately equal to breadth of mesothorax.

Segment 1 is rounded, three-fourths as long as broad; 2 is broad as 1; following segments about three-fourths as thick; segments 3 to 6 are constricted at bases, becoming more stout successively. Color of segments 1 and 2 uniform light brown; 3 to 5 pale yellow at bases, shading to brown at outer ends, each succeeding segment from 3 to 6 becoming darker in color; 6 to 8 are dark brown. Spines upon segments 2 to 5 are of medium size, but not very conspicuous. Color of head varying from gray-brown to yellow-brown.

Prothorax about five-ninths as long as broad and slightly longer than the head; sides rounded, slightly wider at hind than at fore angles; one stout spine at each anterior, and two stouter spines of equal size at each posterior angle; anterior marginal pair of spines about one-half as long as those at front angles; usual row of five spines on each side of hind margin, of which number 4 is equal in strength to those on the front margin. Mesothorax nearly one and one-third times as wide as the prothorax, broadest posteriorly, sides curving outward; mesonotum without conspicuous spines, posterior margin forming an obtuse angle in middle. Metathorax slightly narrower than mesothorax, sides nearly parallel, broader than prothorax at posterior edge; metanotum bears two pairs of spines at front edge, the inner pair as strong as those at front angles of prothorax. Wings present (probably reduced at some season of year), average length about 0.68 mm., not reaching to the tip of the abdomen, breadth equal to about one-thirteenth of their length; fore wing has two longitudinal veins, each bearing stout spines set at regular intervals; fore wings shaded ash gray, hind wings gray only along basal three-fourths of midvein; spines on wing veins dark brown and conspicuous; costa bears 19 to 24 spines; fore vein, 13 to 18; hind vein, 10 to 12; scale, 5; interior of scale, 1; fringe of hairs on costa of fore wing quite heavy, in length exceeding the breadth of the wing. Legs of medium length, lighter than body in color, pale yellow, shaded more or less with brown on upper side of middle of femora and tibiae; a pair of stout brown spines at inside of tip of each tibia, small brown spines scattered along femora and tibiae; spines standing in two rows on inner side of hind tibiae are weak and only about four in each row.

Abdomen nearly cylindrical to eighth segment, then tapering abruptly to an acute tip; color uniformly dark brown; a still darker-colored narrow chitinous thickening extends across dorsal side of segments 2 to 8 near anterior edge. Three or four quite stout and rather conspicuous dark-brown spines stand at each side of dorsal plates on 2 to 8; six rather prominent spines stand in a row on posterior edge of ventral plates 2 to 7; terminal spines stout and prominent; tenth segment split open along dorsal median line.

Biology. Development of the tobacco thrips is gradual, but approaches a complete change (55). Eggs deposited in tissues of the foliage hatch in about 7 days in South Carolina (156). The immature form passes through two larval stages, during which feeding occurs, the two stages requiring 5 to 6 days. According to Hooker (77), the mature larva "crawls to some obscure nook," becomes inactive and pupates.[6] This stage is quiescent and does not feed. At the end of 3 to 4 days the adult emerges and shortly begins feeding. The time for development from egg to adult is approximately 16 days, the period being shorter in warm weather and longer when the temperatures are relatively low.

Breeding of the tobacco thrips is continuous throughout the warmer months. Five overlapping generations have been reported (49) in South Carolina from April 10 to October 18. The female lives for an average of approximately 30 days and deposits 50 to 60 eggs (156). Nonfertile eggs produce males and fertile eggs apparently produce only females (135, 49, 157). Males live for a shorter period than females and are usually less numerous in the field.

The tobacco thrips presumably hibernate under grass or in other protected places. It is possible that intermittent breeding takes place on wild and cultivated host plants during the warmer periods of the winter in the southern range of the insect, but specific evidence on this point is lacking. So far as is known, only the adult females over-winter (49).

Volunteer peanuts are a factor in breeding destructive population of thrips in Alabama, Florida and Georgia. Many peanuts lost at harvest remain in the ground over winter and germinate the following spring. Usually these volunteer plants emerge a few weeks earlier than the regular crop. The thrips multiply on the volunteers and then migrate to the younger plants, where peanuts follow peanuts in rotation. Doubtless other early host plants are also of importance in this respect.

Much additional information is needed on the biology of the tobacco thrips with emphasis on overwintering habits, succession of host plants in relation to injury to peanuts, and development of the insect on peanuts.

Control. Heavy rainfall is one of the most effective natural controls of tobacco thrips. This fact was noted as early as 1907 (77). Predaceous insects are also of value in reducing the population. A true bug, *Triphleps*[7] *insidiosus* Say, was reported as feeding upon *F. fusca* (77). The ladybird, *Hippodamia convergens* Guerin, and a lacewing, *Chrysops*

[6] The closely related species *F. tritici* usually pupates in the ground (157). It is possible pupation of *F. fusca* may occur in the soil as well as on the host plant.
[7] *Orius.*

sp. have been reported as predators of *F. tritici* (157) and these forms probably prey on *F. fusca* also.

Chemical control of tobacco thrips is feasible. The first treatments consisted of nicotine-soap sprays (77, 49) and rotenone (86). Following the use of tartar emetic (108) against onion thrips, *Thrips tabaci* Lind., the material was used on peanuts and other plants in the greenhouse without injury to the crops (3). Tartar emetic sprays were used on peanuts in the field, but the applications were too late for successful control (115). Poos (116) reported successful control with DDT in the form of 2 percent dust, 0.66 percent sprays, and 10 percent aerosols and with tartar emetic sprays. Satisfactory control of tobacco thrips on peanuts with significant increase in yield from the use of DDT and BHC dust and sprays has been reported (120). The most effective treatment consisted of three applications of an emulsion containing 4 percent DDT applied by atomizing at the rate of 10 gallons per acre. The author (5) found 3 percent DDT dust more effective than 20 percent Sabadilla, 1 percent rotenone, or 1 percent nicotine. A spray containing 1.5 percent water-dispersable DDT was much more effective against the thrips than 3 percent dust. In 1948, he reported 2 percent Gamma BHC and 20 percent toxaphene applied as dusts at the rate of 20 pounds per acre gave much better control than 2 percent DDT dust.

Data on gains in yield of peanuts resulting from control of tobacco thrips are somewhat contradictory. One study (120) reported increases as high as 36 percent in the weight of green pods in some experiments and no increases in others. A second study (7) reported an increase in the weight of peanut pods set early on DDT and BHC plots but, as mentioned previously, most of the early crop was lost in the ground at harvest. In a nonreplicated preliminary test 20 percent toxaphene dust applied for thrips and leafhopper control resulted in 810 pounds dry peanuts[8] per acre more than was harvested from undusted peanuts. It appears that gains in yield from control depend upon the severity of the thrips infestation, the efficiency of the control, the type of peanut concerned, fertility of the soil, weather conditions, and other factors. Additional research is needed on these points.

White-Fringed Beetle

Importance. The white-fringed beetle, *Pantomorus leucoloma* (Boh.)[9] is potentially the worst pest of peanuts in southeastern United States,

[8] Seven percent moisture content.

[9] Also known as *Graphognathus leucoloma fecundus* (Buch.); other forms including *Pantomorus* (*Graphognathus*) *peregrinus* Buch., *G. leucoloma striatus* (Buch.), *G. leucoloma dubius* (Buch.) are also of economic importance.

although at present its limited distribution prevents widespread losses to the crop. This pest's first appearance in the United States was in 1936 when it was found causing damage to cotton and peanuts in northern Florida (154, 155). Shortly thereafter it was discovered in southern Alabama. In spite of rigid quarantines and intensive control work which has restricted the dispersal of the pest, it is established[10] in 115 counties in seven Southern States. The infested area in some counties is very small. The distribution of the white-fringed beetle, by States and counties, is given by G. G. Rohwer of the U. S. Bureau of Entomology and Plant Quarantine as follows:

ALABAMA: Baldwin, Chilton, Coffee, Conecuh, Covington, Crenshaw, Dallas, Escambia, Geneva, Jefferson, Lowndes, Mobile, Monroe, Montgomery, Wilcox.

FLORIDA: Escambia, Holmes, Oklaloosa, Santa Rosa, Walton.

GEORGIA: Baldwin, Ben Hill, Bibb, Bleckley, Bulloch, Burke, Candler, Clarke, Clayton, Clay, Cobb, Coffee, Coweta, Crawford, Crisp, DeKalb, Dodge, Dooly, Emanuel, Evans, Fulton, Habersham, Harris, Houston, Irwin, Jasper, Jefferson, Johnson, Laurens, Macon, Monroe, Montgomery, Muscogee, Newton, Peach, Putnam, Richmond, Screven, Spalding, Sumter, Talbot, Tattnall, Taylor, Telfair, Toombs, Treutlen, Troup, Turner, Twiggs, Washington, Wheeler, Wilcox, Wilkinson.

LOUISIANA: Iberia, Jefferson, Orleans, Plaquemines, St. Bernard, St. Tammany, Tangipahoa.

MISSISSIPPI: Attala, Covington, Forrest, Grenada, Hancock, Harrison, Hinds, Jackson, Jefferson Davis, Jones, Lamar, Montgomery, Pearl River, Perry, Pike, Rankin, Simpson, Stone.

NORTH CAROLINA: Anson, Bladen, Brunswick, Cumberland, Craven, Duplin, Jones, Lenoir, New Hanover, Onslow, Pender, Robeson, Sampson, Wayne, Union.

SOUTH CAROLINA: Richland, Fairfield.

The white-fringed beetle is native to Argentina, Chile and Uruguay in South America. It has been introduced into the United States and also into Australia (9, 147).

Larvae of the white-fringed beetle feed upon underground parts of peanuts and damage the stand and yield. Adults feed upon the foliage. Uncontrolled, heavy infestation may cause a complete loss of the peanut crop. One report (170) showed an average of 283 larvae per square yard in peanut fields and upon emergence as high as 44 adults on one plant. In addition to peanuts, the insect feeds upon several hundred other species of plants,[11] including cotton, velvetbean, soybean, lespedeza, lima bean, okra, sweet potato, cowpea, chufa, corn, tomato, clovers, many ornamentals, and numerous other cultivated and wild plants.

Description of stages. The adult white-fringed beetle was originally

[10] 1948.
[11] Two hundred thirty-four specimens in one locality in Alabama (147).

described in 1840 by Boheman as *Naupactus leucoloma.* In 1939, Buchanan (20) placed the insect in the genus *Pantomorus* and described it from specimens collected at Florala, Alabama. Very brief descriptions of the egg and larva have been made by several investigators.

Egg

The egg is approximately 0.9 mm. long and 0.8 mm. wide, and is oval in shape. The color when freshly deposited is milky white; the color changes to dull light yellow after 4 or 5 days.

The eggs are deposited in masses, ranging in number from a few to as high as 60 or more, but the usual number is from 15 to 25. The individual eggs and masses are covered with a gelatinous substance which makes them adhere to one another and to objects or the soil.—Young *et al.* (170).

Detailed technical descriptions of the larva are not available to the writer. A very brief description by Young *et al.* (170) follows:

Larva

The full-grown larva averages approximately one-half inch in length. The body is yellowish white, fleshy, more or less curved, legless, and sparsely covered with hair. It consists of 12 much-folded segments, which are interrupted by two sub-lateral longitudinal grooves running the length of the body. The dorsal portions of the segments are bulging; the ventral portions are flat. On the sides, above the longitudinal separating grooves, small spiracles are present on all segments except the second, third, and twelfth (last).

Anderson (2) has published a key with drawings for separating *Naupactus (Pantomorus) leucoloma* from related species. This key is reproduced below:

1. With a group of several spinules dorsally on stipes at proximal end of the longitudinal row of strong setae of maxillary mala.. 2
   Without spinules at proximal end of the longitudinal row of strong setae of maxillary mala..*Pantomorus godmani* (Cr.)
2. Eusternum of mesothorax with minute spinules[12] between and behind the two sternal setae. Scutellar setae I, II, and IV on the first four abdominal segments slender and awl-shaped (= subulate)..............*Artipus texanus* Pierce
   Eusternum of mesothorax without minute spinules.[12] Scutellar setae I, II, and IV on the first four abdominal segments stout and spindle-shaped (= fusiform) 3
3. Margin of posterior third of head capsule broadly arched. Paired epipharyngeal sclerome distinctly U-shaped, basal part with distinct anterior margin which forms a clear-cut angle with exterior margin of inner arm, and with inner arm about twice as long as antero-posterior extent of base .. *Naupactus,* n. sp.
   Margin of posterior third of head capsule ogival. Paired epipharyngeal sclerome not distinctly U-shaped, basal part with obliterated anterior margin, exterior margin of inner arm roundly connected with interior margin of

[12] The presence or absence of these spinules can be ascertained readily on specimens treated with caustic potash and on uncleared specimens when properly lighted, by studying them with a magnification of about 75 diameters.

outer arm, and with inner arm not longer than antero-posterior extent of base...*Naupactus leucoloma* Boh.

Adult

Buchanan's 1939 description of the adult follows:

Length, 8-12 mm. Brownish gray to gray, apical declivity of elytron usually paler than disk, the latter sometimes indistinctly variegated with gray and pale brown. Scales moderately dense, setae long and conspicuous, elytral scales in general broader than those on head and pronotum; elytral setae of unequal lengths, the longer ones fine, often somewhat kinky apically in dried specimens and two or three times as long as the shorter ones, the latter brown to whitish; elytral puncture rows, at low magnifications, appearing as narrow, dark lines.

Vestiture on head and rostrum brownish in general, white above and below eye and on side of rostrum below scrobe, the scales on subapical area and on mandible very small, often somewhat coppery or greenish, the setae on front inclined, those above eye and on rostrum above suberect; nasal plate with its posterior margin elevated; median groove much widened anteriorly, the widest portion sometimes about one-fourth width of dorsum of rostrum; scape reaching hind margin of eye, funicular segment 2 considerably longer than 1, often nearly twice as long, longer than 3 and 4 together; eye distinctly elliptical. Prothorax wider than long (about 7 to 5), sides broadly and subevenly rounded; pronotum with broader white and narrower brownish scales, the white ones forming a narrow, median line toward apex and base (rarely complete), a curved, often indistinct, stripe beginning opposite elytral interval 3, and a lateral stripe which is often incomplete anteriorly, the disk sometimes with small, vague, scattered, whitish spots; pronotal setae curved, inclined on disk, more nearly erect laterally; pronotum (with scales removed) irregularly punctate and feebly rugo-granulate, median groove feeble or obsolescent. Elytral intervals faintly convex, each with about 3 or 4 confused rows of setae, the longer ones more abundant on apical declivity, the length of each longer seta equal to or greater than the width of the interval; white stripe covering interval 7 throughout, about apical two-fifths of interval 6, and basal half or more of interval 8, the stripe bordered mesad (on striae 5 and 6) by a broken, usually indistinct dark line, and bordered laterad (on stria 8) by a narrow, blackish line. Body beneath scaly and setose, the setae longer and more nearly erect medially, the abdominal scales progressively finer from base to apex, abdominal vestiture sparser medially; metasternum a little longer than in *peregrinus*. Legs with abundant, mostly setalike, prostrate and suberect vestiture; fore tibia with short, well separated denticulations; posterior face of hind tibia with a usually distinct ridge from base to about middle.

Biology. Only one generation of the white-fringed beetle occurs annually. The eggs are deposited on the surface of the ground, usually on or next to debris (sometimes in the soil) during the summer and fall. All adults are females and each beetle deposits an average of slightly less than 800 eggs. The eggs develop parthenogenetically, hatching in about 2 weeks during warm weather. The larvae pass the winter in the soil and cause damage to crops, principally the following spring and summer. It is at this time the stand of peanuts may be seriously damaged. Adults

emerge from May until November (169), the peak of emergence coming in July. Rainfall stimulates emergence. The beetles feed a few days and gradually disperse over the nearby areas. Since the elytra are fused together and the insect cannot fly, dispersal is by crawling and the distance traveled is less than 1 mile. Eggs are deposited and the adults die 2 or 3 months after emergence. Apparently few beetles over-winter in southern Alabama (169, 170) but adults have been found throughout the winter in the vicinity of New Orleans, Louisiana (91).

Control. Natural enemies are apparently of minor importance in control of white-fringed beetles. Strong (141) reported that no natural enemies of *P. leucoloma* had been found in studies through 1938-39. Glaser *et al.* (61) reported a nematode, *Neoaplectana glaseri* Steiner, parasitizing *P. leucoloma* and related insects. Swain (142) reported *N. glazeri* attacking *P. peregrinus* and *P. leucoloma;* also *N. chresima* Steiner in *P. peregrinus.* Later he reported (143) *Diplogaster* sp. capable of parasitizing white-fringed beetles, but of minor importance.

Much of the first control work on white-fringed beetle was in the nature of locating infestations, confining the insect in local areas, suppressing and, if possible, eradicating it. Federal and State quarantines have been in force and clean-up campaigns have been conducted. Research stations have been established at Florala, Alabama; Gulfport, Mississippi; New Orleans, Louisiana; Fort Valley, Georgia; and other localities, by the U.S. Bureau of Entomology and Plant Quarantine in cooperation with State agencies.

Much progress has been made in the control of this insect on peanuts and other crops in recent years. Calcium arsenate and cryolite dusts, clean cultivations, herbicides for the destruction of wild host plants, and the use of soil fumigants such as methyl bromide and carbon disulfide were among the first control recommendations (111). More recently DDT has shown great promise. DDT has been reported (166) to be 69 to 74 times as effective as cryolite. As little as 0.125 pound of DDT per 100 gallons of spray gave a higher kill on peanut foliage than 12.5 pounds of cryolite (165). In experiments at Florala, Alabama, (167, 168) 5 pounds technical DDT per acre, in the form of a dust or dissolved in zylol and mixed with the upper 3 inches of soil, gave complete mortality of newly hatched larvae. Smaller dosages gave complete mortality of summer-hatched larvae, but not of those hatched in late fall. When mixed with the soil at the rate of 10 pounds per acre and above, DDT gave complete mortality of newly hatched larvae the year following application, i.e., the second year. In the presence of white-fringed beetle larvae, pea-

nut plants on soil treated with DDT at rates of 25, 50 and 100 pounds per acre, yielded 48 percent more peanuts than those on untreated soil. Thus it appears that control of white-fringed beetle on peanuts by treatment of the soil with DDT is feasible. Dusting the foliage of peanuts to kill the adults is also feasible but, where soil treatments are employed, may not be necessary. Incidental control may be had by dusting for control of potato leafhopper.

Information available on the control of white-fringed beetle has been summarized (68). DDT is the most effective insecticidal treatment known for control of the pest. It may be applied to the soil for control of larvae or to the foliage of plants for control of adults. Ten pounds of technical DDT per acre has remained effective in the soil during a 5-year period, and the tests are still in progress to determine the length of effectiveness.

The insecticide may be applied as dusts or sprays. For spraying, 50 percent wettable powder in concentrations of 2.5 to 5 percent has been most effective.

In treatment of foliage to kill adults of the white-fringed beetle, DDT should be applied at the rate of ½ to 1 pound of technical per acre at 2- to 3-week intervals during the season of beetle emergence. The insecticide may be applied in the form of dusts or sprays. Sprays are usually prepared from wettable powder or emulsifiable concentrates.

Since the major part of the research on white-fringed beetle is being conducted by the U. S. Bureau of Entomology and Plant Quarantine, this agency should be consulted for latest recommendations on control.

Only limited information is available on the effect of rotation and other cropping practices on control of the white-fringed beetle. Additional research is needed on these points. Additional information is also needed on the long-time effect of soil treatments with DDT on productivity, soil organisms, fish and wildlife, and water supplies.

Soil Insects

Several species of soil insects attack peanuts and cause an undetermined amount of damage. In addition to the white-fringed beetle, which is discussed in another section, damage to underground parts is caused by several species, including southern corn rootworm, larvae of the banded cucumber beetle, two species of wireworms, white grubs, and the lesser cornstalk borer.

One of the first references of damage to peanuts by soil insects was made by Fink (56), who found southern corn rootworm, *Diabrotica du-*

odecimpunctata (F), attacking young peanut pods in Virginia; the nuts within the pods were devoured. Following this report, peanut damage from this insect received little attention until recent years. An average of 12 to 28.1 percent of the pods was reported as injured during 1945 and 1946 in a study made in Virginia (64). *D. duodecimpunctata* and larvae of the related species, *D. balteata* Lec., were found attacking peanut pods in Alabama (5). Because of the difficulty of distinguishing between the two closely related species of larvae, no attempt was made to determine relative abundance. However, the large number of recently transformed *D. balteata* adults found in pupal cells in the soil around the peanuts indicated this species was the predominant one. In 1947 Arant (5) observed as high as 35 percent of the pods injured in some fields, but in this instance a wireworm, *Heteroderes* sp. appeared to be doing much of the damage. Other soil pests appear to be of less importance.

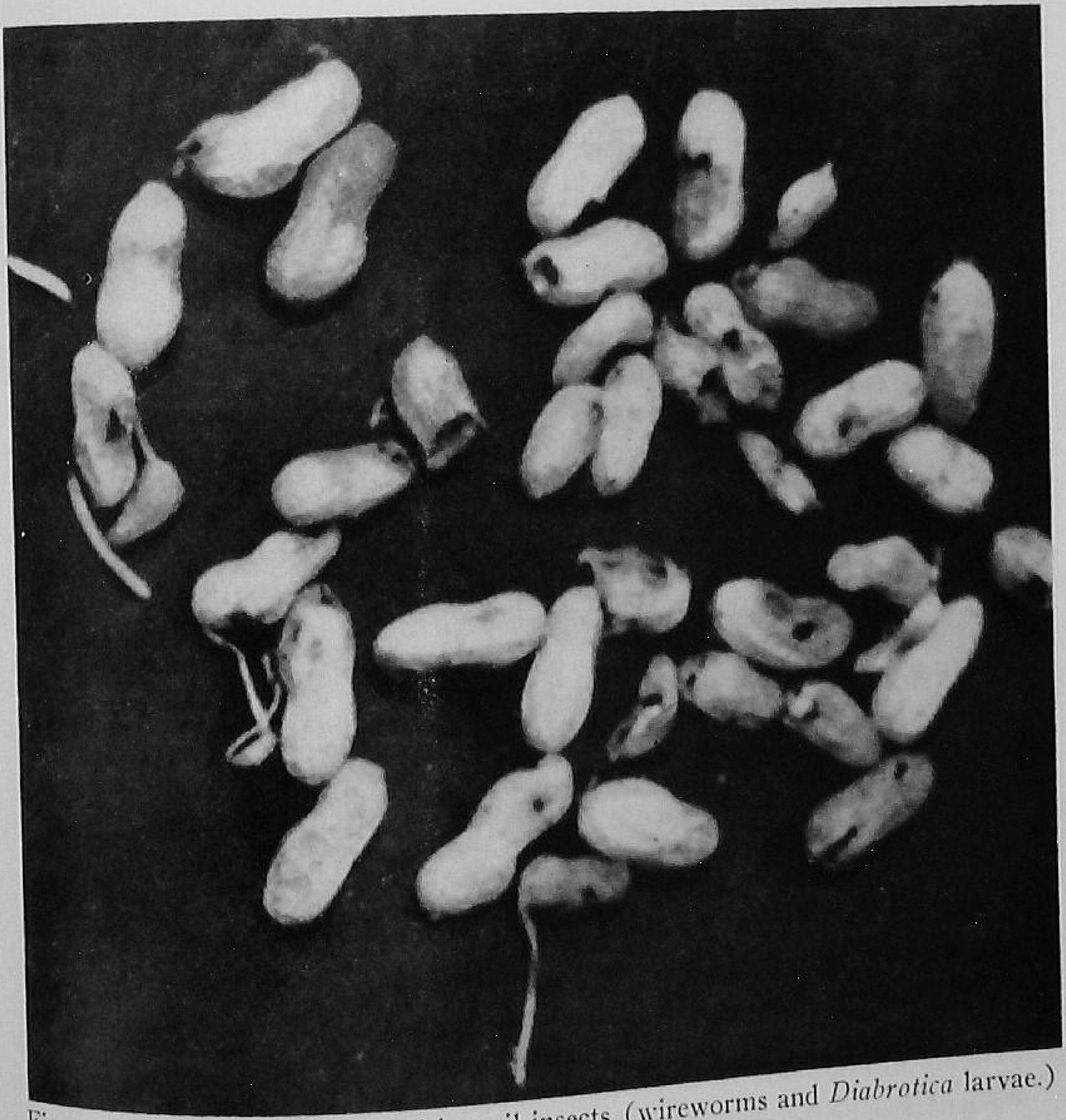

Figure 4. Peanut pods damaged by soil insects (wireworms and *Diabrotica* larvae.)

Southern Corn Rootworm. This insect is the larva of a 12-spotted leafbeetle, *Diabrotica duodecimpunctata* (F), commonly called the spotted cucumber beetle. The life history and habits of the insect are well known (144, 82, 4, 137). Both adults and larvae are polyphagic in their feeding habits, several hundred species of plants serving as hosts. The foliage of cucurbits and many of the legumes are among the preferred foods of adults. Eggs are deposited in the soil and the larvae develop upon underground parts of many plants including young corn and the pods of peanuts. The time for development from egg to adult is 30 to 40 days during warm weather. Adults over-winter only in the Southern States. During the summer months, many adults migrate northward and cause damage to cucurbits and other crops.

The extent of the damage caused by this species to peanuts has not been clearly evaluated. Apparently the insect is more destructive in Virginia than in Alabama.

Banded Cucumber Beetle. The banded cucumber beetle, *D. balteata* Lec. is a pest of beans, vetches, cucurbits, alfalfa, tomatoes and many other vegetables, fruits and ornamental plants. It is restricted to warm climates, occurring in the U. S. in the Gulf Coast States and California. It is distributed in Alabama from the central part of the State southward (127). The insect is found in the northern extremities of its range only in late summer and fall.

The banded cucumber beetle has been known in Mexico for many years. In 1905 it was found in Texas (29) and in 1922 in Alabama (127). Little is known regarding the habits of the larva. It will feed on underground parts of peanuts, corn, string beans, and doubtless many other plants. Using corn as food for the larvae Robinson (128) found that approximately 30 days were required for development from egg to adult during warm weather. The number of generations, seasonal abundance, overwintering habits, and food preferences of larvae and adults in the peanut-growing areas are largely unknown. There is a need for additional research on this insect and an evaluation of its damage to peanuts.

Wireworms. Wireworms of the genus *Heteroderes*[13] were found by the writer damaging peanut pods in Alabama in 1947. Larvae of the genus *Cebria*[13] were also collected from peanuts.

The wireworm, *Heteroderes laurentii* Guer., is widely distributed in the Southeastern States and causes economic damage to a variety of crops, including corn, snapbeans, potatoes, lespedeza and sweet potatoes (31). So far as the writer is aware, there is no record of damage from *Cebria* sp. in Alabama or adjoining States.

[13] Identification by Dr. W. H. Anderson, U. S. Bureau of Entomology and Plant Quarantine.

Although definite proof is lacking, it is probable that *H. laurentii* is the species which attacks peanuts. Unlike some wireworms, this species completes its development within one year. It prefers cultivated lands to sod areas. This and other species of the genus *Heteroderes* are limited to tropical and subtropical areas (87).

The major facts regarding wireworm damage to peanuts are yet to be determined.

White Grubs. The larvae of *Strigoderma arboricola* (F.), have been reported doing serious damage to peanuts in Virginia (105). The grubs attacked the peanut pods and often devoured the nuts. Soil fungi (*Rhizoctonia*) apparently invaded the pods through abrasions in the shell and caused rotting of the peanuts. The damage was more severe on soils fairly high in organic matter. The grubs caused 85 percent loss in some fields.

The adult of these grubs is a beetle (Rutelid) 10 to 12 mm. long. The head, thorax and scutellum are blackish green in color and the elytra are dull brownish yellow (18). The beetles feed on the flowers of wild and cultivated roses and on blackberry blossoms and fruits. On collecting adults from many other plants, Grayson (63) concluded that neither the larva nor the adult was host specific for peanuts, and that grub damage to peanuts in Virginia was of a minor nature during 1944 and 1945.

Lesser Cornstalk Borer. The lesser cornstalk borer, *Elasmopalpus lignosellus* (Zell.), is widely distributed over southern United States, Mexico and South America. The larva is slender and greenish in color with indistinct transverse bands of a lighter color on the anterior margin of each segment; it is usually a little less than one inch long when mature. The adult is a yellowish brown to blackish-colored moth with a wing expanse slightly less than one inch.

The larva feeds on corn, beans, cowpeas, sugar cane, peanuts, sorghum and many other crops. Damage is caused by the insect tunnelling in the stem of the host plant. When not feeding, the larva usually rests in a tube-shaped web near the surface of the soil. Crops on thin sandy soils are injured most seriously. Four generations a year have been reported in South Carolina and Mississippi, each requiring 4 to 5 weeks (94, 95).

There is a strong belief in southern Alabama that the lesser cornstalk borer is a serious pest of peanuts. Presumably the pest bores in the stems, killing branches or entire plants. During two seasons, the writer has not been able to find any serious damage to peanuts which could be definitely attributed to lesser cornstalk borer. It is well known, however, that the population of this species reaches destructive levels only at inter-

vals over a period of years (95). It is possible that serious destruction does occur during some seasons.

Other Soil Insects. Several insects not previously discussed are recorded in the literature as attacking the pods and underground parts of peanuts. These records include the following: Japanese beetle, *Popillia japonica* Newn., attacking peanuts in Japan (159) and a potential pest in the United States; termites in many parts of the world; a mealybug, *Pseudococcus* sp. on peanut roots causing severe damage in Puerto Rico (138); mealybug, *P. solani* Ckll., occurring on peanut roots but causing little damage in Florida (23); pineapple mealybug, *P. brevipes* (Ckll.) on peanut pods in Tanganyika (67); citrus mealybug, *P. citri* (Risso), and also *Phenacoccus hirsutus* Green on roots of peanuts in Egypt (78); larvae of the yam beetle, *Heteroligus claudius* Klug., killing as high as 70 percent of seedling peanuts in the Province of Nigeria (88); two ants, *Solenopsis fugax* Latr. and *Tetramorium coespitum* L., a mole cricket, *Gryllotalpa gryllotalpa* L., and three species of beetle larvae, *Pentodon idiota* Hbst., *Agriotes gurgistanus* Fald., and *Podonta daghestanica* Reitt in North Caucasus (132); the mole crickets, *Scapteriscus acletus* R. & H. and *S. vicinus* Scudd., on peanuts in southeastern United States (163); two ants, *Eciton caeca* Latr. and *Ectatomma ruidum* Roger, in Central America (21); the earwig, *Euborellia stali* Dohrn, causing as high as 20 percent damage to peanut pods in southern India (25); several species in Senegal including termites, *Termes natalensis* Hav. and *T. bellicosus* Semath which gnaw pods, and *Odontotermes vulgaris* Hav. which attacks the nuts themselves; white grubs, *Schizoncha africana* Cast., *Anomala plebeja* Ol., *Adoretus umbrosus* F., and *Podalgus* (*Crator*) *cuniculus* attacking underground parts; the beetle, *Scydmaenus chevalieri* boring into pods and the ants, *Monomorium bicolor* Em. and *Dorylus fulvus* Westu. eating seeds of perforated pods (131).

Control. Few studies have been made on control of insects attacking underground parts of peanuts. Soil treatment with DDT and benzene hexachloride has been found to reduce southern corn rootworm injury to corn (60). Results of control experiments on southern corn rootworm on peanuts in Virginia (64) showed that DDT applied to the soil at the rate of 50 pounds of technical material per acre resulted in a reduction of 61 to 68 percent in the number of pods injured; yield records were not taken. The writer (5) found that soil treatment with DDT, BHC, chlordane and toxaphene reduced the injury to pods by soil insects on replicated plots in Alabama. In 1949, he found that dusting with toxaphene or DDT reduced damage from *Diabrotica* larvae (8). Effective control

is reported by Fronk and Dobbins (59) from soil applications of 1 to 1½ pounds gamma benzene hexachloride, 5 pounds parathion, 40 pounds toxaphene, or 67 pounds DDT. Additional research is needed on soil insects, their economic status, and control.

Insects Attacking Peanuts and Peanut Products in Storage

A host of insects attack peanuts and peanut products in storage, some times causing severe damage. Some damage may occur in storage on farms, but the major losses are to buyers, processors, wholesalers, and retailers of peanuts and products derived from them. Insect infestations are much heavier in peanuts after they are shelled (121, 17). Salted peanuts, peanut meal, peanut butter, candies and other confections are readily infested by insects and the peanut trade must continuously combat these pests.

Many of the forms infesting grain, milled products, dried fruits and other foods also attack peanuts. The exact number of species infesting peanuts is not known, but over 50 species infest grain and grain products (11). Among the more important stored-products pests attacking peanuts are Indian meal moth, almond moth, saw-toothed grain beetle, flour beetles, cadelle, dermestids and others.

So far as the writer is aware, no adequate estimates are available on annual insect damage to peanuts and their products in storage. A 3-million-dollar loss in the United States was estimated in 1911 (121). In 1943 the Food and Drug Administration (58) reported that, of the 7 million pounds of imported nuts[14] examined in 1943, over 5 million pounds were denied entry because they were wormy or damaged. The major reason for the high percentage of rejections was insect infestation in large shipments of peanuts from Africa.

Different species of insects infesting stored peanuts and peanut products vary greatly in actual damage caused. However, heavy insect infestations render the products unfit for the edible trade regardless of the extent of destruction wrought.

Indian Meal Moth. The Indian meal moth, *Plodia interpunctella* (Hbn.) is a handsome moth with a wing expanse of nearly ¾ inch (11). The fore wings are reddish brown with a coppery luster on the apical two-thirds; the proximal third is whitish gray; the hind wings are dusky gray. The larva is a dirty-white caterpillar often with a pinkish or greenish tint; when full-grown, it is about ½ inch long. According to Popenoe (121) this is the most important insect pest of stored peanuts in the

[14] Several kinds, including peanuts.

United States. It also causes damage to peanuts in many other parts of the world (131, 103, 140, 109, 96, 22). Larvae of the Indian meal moth feed upon shelled peanuts and spin silken threads which form a matted web. Broken kernels are preferred by this species.

Almond Moth. The almond moth,[15] *Ephestia cautella* (Walk.), is a pest of nuts, dried fruits and other products including peanuts. The adult has a wing expanse of about ¾ inch. The fore wings are narrow, especially at the base, grayish to yellowish in color with dark markings which may appear as zigzag lines or suffused bands across the wings; hind wings are whitish (30). The larva is a whitish caterpillar which may be tinged with pink and green; it is cylindrical and about ½ inch long when fullgrown; dark dots in four pairs of rows give the body a striated appearance. The larvae spin silken webs which may appear as masses intermingled with food and excrement. In 1911 peanuts were listed (30) as a stored product attacked by larvae of the almond moth. Since then this species has been found causing economic damage to peanuts in many sections of the world. Almond moth has been reported (17) as very destructive in Georgia. Other reports include those for Senegal (131), Spain (134), Gold Coast (33) and Britain (62).

Saw-toothed Grain Beetle. Both larvae and adults of the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.), attack peanuts and products derived from them. Bissel and DuPree (17), found this insect to be the most abundant species[16] in shelled peanuts in Georgia; Popenoe (121) listed it third in importance among stored peanut pests. It is recorded infesting peanuts in other parts of the world (10, 130). The adult saw-toothed beetle is about 1/10 inch long and brownish in color; the thorax bears 6 saw-tooth-like projections on each side. The whitish larva has a brown head, is small, slender, and slightly longer than the adult. Adults of the saw-toothed grain beetle have been kept alive over 3 years; the average life is 6 to 10 months. Two related species, *O. bicornis* (Er.) and *O. mercator* (Fauv.) occur in this country. The latter species is known to infest peanuts in Senegal (131). Both have feeding habits similar to that of *O. surinamensis.*

Flour Beetles. At least two species of flour beetles of the Genus *Tribolium* attack stored peanuts and products derived from them. The red flour beetle, *T. castaneum* (Hbst.), and confused flour beetle, *T. confusum* Duv., were fairly numerous in shelled peanuts (17). The former species has been considered (121) as second in importance among

[15] Also called fig moth.
[16] Other than psocids.

stored peanut pests in the United States. The two forms have been recorded in peanuts from other parts of the world (Roubaud, (131), *T. castaneum* and *confusum* in Senegal; Jarvis, (83), *T. castaneum* in Australia; Fletcher, (57) and Roepke, (130), *Tribolium* sp. in Pusa and Java; Okuni, (110), *T. castaneum* in Formosa). The flour beetles are elongate, reddish-brown insects about 1/7 inch long. The larvae are brownish white and somewhat flattened in appearance. Adults of the two species may be distinguished by the following differences:

As viewed from the underside of the head, the eyes of the confused flour beetle are separated by about three times the width of either eye, whereas the width of each eye as seen from below in the red flour beetle is about equal to the distance between them. The confused flour beetle has antennae gradually enlarged toward the tip, the red flour beetle suddenly enlarged at the tip; the margin of the head is notched at the eyes in the confused flour beetle and not so notched in other species. (101).

Adult flour beetles may live 2 years or more, but the average life is about 1 year (11).

Cadelle. The cadelle beetle, *Tenebroides mauritanicus* (L.), appears to be of importance in peanuts, although literature references to infestations are scarce. It has been listed (121) as fourth in importance among stored peanut pests, and has been found to be one of the more common forms in shelled peanuts stored in jute bags (17). Roubaud (131) reported it infesting stored peanuts in Senegal. The adult is an oblong, flattened beetle, black in color and measuring about 1/3 inch in length. The larva is dirty-white with the head, thoracic shield, and two horny points at the tip of the abdomen black; it is about ¾ inch long when full-grown. This insect is primarily a pest of grain and flour mills. The larvae sometimes bore into wood. Average life of the adult is 1 to 2 years. The extent of its damage to peanuts needs further investigation.

Dermestids. Several species of dermestids infest peanuts. Among the forms recorded in the literature are *Trogoderma bicolor* Arrow in peanuts imported into Holland (24); *Dermestes lardarius* L. in peanuts in Europe (173); *Attagenus gloriosae* imported into Holland (not established) in peanuts (74); unidentified species of dermestids common in shelled peanuts stored in jute bags in Georgia (17). The dermestids are small beetles that are for the most part scavengers, feeding upon animal matter. Forms that feed on plant products probably supplement the diet with dead bodies of other insects (11). Thus, it would appear that the

principal damage to peanuts by these pests might be spoilage of products intended for the edible trade.

Other Pests of Stored Peanuts. The Mediterranean flour moth, *Ephestia kuehniella* Zell. may cause economic damage to peanuts. Larvae of this species were considered by Popenoe (121) as sixth in importance among stored peanut insects. However, the writer has found no additional references to this insect infesting peanuts, although it is distributed over many parts of the world.

Bruchids attack peanuts in storage, mostly in foreign countries. *Bruchus chinensis* L. attacks peanuts in Java (129). *Pachymerus acaciae* Gyll. is reported (40) as infesting peanuts and as having spread from Asia to Greece, Italy and the north and west Coasts of Africa. This species is recorded as attacking stored peanuts in Senegal (26) with 59,000 tons of peanuts being destroyed by it (145). Howard (79) referred in a general way to fumigation as a means of protecting peanuts against pea and bean weevils. However, this is the only reference found indicating bruchid injury to peanuts in the United States and it is concluded that such damage is not common.

The flat grain beetle, *Laemophloeus minutus* (Oliv.), a sap beetle, *Carpophilus* sp., the cigarette beetle, *Lasioderma serricorne* (F) and numerous psosids were found (17) in stored peanuts in Georgia and were suspected of being injurious. Other reports include a sap beetle, *Carpophilus* sp., in peanuts in Australia (83); a relative of cigarette beetle, *Lasioderma testaceum* in peanut cake in Pusa; sap beetles, *C. ligneus* Murr., *C. hemipterus L.*, and *C. decipens,* attacking peanuts in Europe (172) and *C. obsoletus* in Japan (75). All of these insects are cosmopolitan in distribution. With the exception of the cigarette beetle, they are probably incapable of damaging sound peanut kernels but may thrive in peanuts already damaged by other insects or in certain products derived from peanuts.

Five hundred tons of peanuts, imported into California from China, were reported as destroyed by *Aphomia gularis* Zell. of the family Galleridae (43). This species closely resembles Mediterranean flour moth.

Additional reports of infestation in peanuts include the following: Tobacco (currant) moth, *Ephestia elutella* (Hbn.), injuring peanuts in Zomba (99), infesting peanut cake in Senegal (84) and in France (85), and infesting peanuts imported into California from China (44); *Sitophilus oryza* (L.) in shelled peanuts in Fiji (90) and in Georgia (17); *Alphitobius diaperinus* (Panz.), *A. piceus* Ol., and *Corcyra*

cephalonica Staint. in Senegal (131); *Homoeosoma vagella* Z. in Australia; *Embia* (*Monotylota*) *vayssierei* Navas in stored peanuts in Senegal (123); *Sitotroga cerealella* (Oliv.), Angoumois grain moth, and *Tenebrio* sp., (meal worm) in stored peanuts in the United States (17).

Control. Natural enemies are of value in controlling pests of stored peanuts, but the species of hosts and parasites involved are so numerous and varied that a detailed discussion here is not feasible. Among the more important parasitic and predaceous forms are *Microbracon hebetor* (Say), *M. jugeandis* Ashm., *Idechthis canescens* (Grav.), *Omorgus frumentarius* Rond., and *Scenopinus fenestralis* (L.) (136, 11).

Sanitation and proper bagging have been found helpful in preventing insect damage to stored peanuts. Bissell and DuPree (17) found that peanuts could be protected from serious infestation by storing them immediately after shelling in cotton bags made from heavy material having 60 threads by 104 threads per inch. Jute bags counting 11 or 12 threads per inch did not give satisfactory protection. For maximum protection, properly bagged peanuts should be stored in clean, insect-free bins. To free bins, storehouses, boxcars and the like of insects, the walls, floors and ceilings may be sprayed with DDT in a 5 percent solution in light oil (36, 37) or in the form of a 5 percent emulsion in water.

Heat and cold have been employed satisfactorily in preventing insect damage to peanuts and peanut products in storage. It was found (19) that a temperature of 125° F. for 6 hours destroyed insects in loose piles of dry peanuts without injury to the peanuts. Also it was reported (36) that a temperature of 120° to 130° F. maintained in all parts of flour mills for 10 to 12 hours destroyed all insect life. Forced circulation of air was necessary to maintain proper temperature throughout the treated area. The use of heat is limited by facilities for maintaining suitable temperatures within masses of stored products. Refrigeration is also effective in preventing insect damage. Protection against insect infestations has been reported when peanuts and peanut products are stored at 50° F. or below (164). The keeping qualities of the products were also enhanced.

Fumigation is perhaps the most feasible method of destroying insects in stored peanuts, once they are infested. Materials which have been used for this purpose include carbon disulfide and hydrogen cyanide (19, 33), a mixture consisting of three parts ethylene dichloride and one part carbon tetrachloride (80), ethylene oxide, 4 ounces plus 2.8 pounds of carbon dioxide per 100 cubic feet in a vacuum tank filled with peanuts (34), and methyl bromide (97, 139). Chloropicrin has been found effective, but it is absorbed and increases the acid content of the peanuts as

much as 300 percent (40); absorption may be reduced by using carbon dioxide with a smaller dose of chloropicrin (34).

Of the several fumigants in common usage, methyl bromide is probably the most desirable for fumigating peanuts and peanut products, provided tight masonry storehouses, vaults or fumigation chambers are available. This gas is noninflammable, is highly toxic to insects, and penetrates well into bagged commodities or other masses of stored products. It is highly toxic to warm-blooded animals and is almost odorless. Well-trained personnel are required for fumigation with methyl bromide. The gas is usually introduced through pipes or tubes from cylinders of the liquid material, placed outside. The rate of application is 1 to 1½ pounds per 1,000 cubic feet where masses of stored products must be penetrated. After an exposure of approximately 24 hours, the chamber should be ventilated. In general, metal and wooden buildings are not suitable for fumigation with this material. For additional information on the use of methyl bromide, the reader is referred to the Supplement to USDA Circular 390 (39) and to USDA Circular 720 (37).

Stored peanuts in tightly constructed metal or wooden buildings may be fumigated with a grain fumigant containing three parts ethylene dichloride and one part carbon tetrachloride, applied at the rate of 4 to 5 gallons per 1,000 bushels of stored product (35).

A considerable amount of the information on control of insects in stored peanuts was developed by research on these pests in other products. Additional research is needed, particularly on the effect of fumigants, refrigeration and heat treatment on peanuts and peanut products as well as the insects involved.

Miscellaneous Pests

In addition to the insects discussed in this paper, numerous minor pests have been observed attacking peanuts in various parts of the world. No attempt is made to cover all of these pests, and no claim is made that the publication is in any sense complete.

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CHAPTER VIII

PEANUT DISEASES

By

KENNETH H. GARREN[1] AND COYT WILSON[1]

In the early years of its cultivation, the peanut was considered somewhat disease resistant. In 1895, after peanuts had been an important crop for a half century, a bulletin (55) on peanuts, published by the U. S. Department of Agriculture, made no specific mention of diseases. Revisions of this bulletin, dated 1909 and 1917, described peanuts as remarkably free from disease. Leafspot was mentioned but damage was regarded as unimportant except in low or poorly drained portions of fields (15, 16).

As peanut production increased, diseases began to attract more attention. There began, therefore, an Era of Exploration. During this period numerous peanut diseases were observed and recorded, many of which never appeared again in the literature. The next era was notable for concentrated study of a few diseases of outstanding local importance. Among such diseases were: Bacterial wilt in the East Indies, rosette in Africa, and leafspot in the southern United States. Overlapping this Concentrated Era was a fourth or General Era which resulted in the publication of reviews of peanut diseases, either from a world-wide (86) or strictly localized viewpoint (64, 98, 99).

At the present time interest in and the study of peanut diseases appear to be in this general phase. During the years 1941 to 1945 the acute shortage of vegetable oils focused attention on peanut culture in the United States and numerous surveys of peanut diseases were made. As a result of these surveys there developed the concept that many diseases other than the obvious ones are found in peanut fields, and that, while the damage caused may be considerable (125), it is difficult to estimate the specific damage to be attributed to individual diseases.

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Peanut Diseases of Major Importance in the United States

DISEASES AFFECTING STAND ESTABLISHMENT

Spotty stands of peanuts are common in the southeastern United States (124) and other peanut-producing regions (43, 64). Since production costs per ton are largely a function of area cultivated, these poor stands are important considerations in the economics of peanut production.

Several things may account for spotty stands. The principal causes appear to be: (A) Poor seed stocks (old seeds, improperly stored seeds, seeds with fungus damage or mechanical injury, etc.). (B) Over-stretching of seed supply or improper spacing of seeds. (C) Inferior planting equipment. (D) Unfavorable conditions after planting. (E) Depredations of field mice, birds, and other animals. (F) Seed rots and seedling blights.

Consideration of these items shows that disease is not the sole factor causing poor stands.

A number of distinct diseases affect peanuts early in the growing season. When considered individually, many of these diseases do not appear to be of importance. Collectively, however, they often are serious. Of these, the pre-emergence diseases probably have the most direct effect on stand establishment in the southeastern United States (163).

Pre-Emergence Diseases

Importance. Soil rot of seeds is regarded as one of the three most important peanut diseases in Rhodesia (64). Its importance in the southern United States must be obtained indirectly, primarily from the emphasis placed on control programs in recent years. The most concrete evidence may be obtained from reports of increased emergence of 15, 25 or up to 40 percent following such control programs (43, 45, 46, 103).

Description. Planted seeds and very young plants are subject to two types of diseases before emergence. The entire seed may be decayed, or the developing embryo of young plant may be attacked by saprophytic fungi, or damping-off fungi. Both of these types of pre-emergence diseases have been reported on peanuts (43, 102, 105).

Organisms. The organisms associated with pre-emergence diseases have not been studied extensively. Soil-borne parasitic and saprophytic fungi may decay seeds, particularly if germination is delayed or if the seed

is damaged. In addition to these soil fungi a fungus flora becomes associated with the peanut fruit as it develops in the soil (162), is present at harvesting (48, 114), and is still present in or on fruits and seeds after storage (41, 67, 111, 149). The majority of species of this fungus flora are saprophytes such as *Aspergillus* spp., *Rhizopus* spp., *Penicillium* spp., and *Fusaria,* but some are definitely parasites such as *Pythium* spp. (111), *Sclerotium rolfsii* Sacc. (149), and parasitic *Fusaria* (41).

Control. Losses from pre-emergence diseases of peanuts may be significantly reduced by seed treatments (45, 46, 51, 64, 103, 105, 155), though in a few instances seed treatment for peanuts has not been considered worthwhile (67, 76, 151). Properly applied seed fungicides will be effective against seed-borne saprophytes and parasites, and if germination is not unduly delayed by adverse weather conditions these fungicides will also be effective against soil-borne fungi (105). Most of the beneficial results of seed treatment of peanuts is due to prevention of decay prior to germination (102, 163).

Increases in emergences from machine-shelled seeds of 25 percent or more are not unusual following seed treatment, and it has been estimated that North Carolina farmers save around $125,000 annually by using treated machine-shelled seeds in preference to hand-shelled seeds (103). Table 1 gives some comparative emergences for treated and untreated machine-shelled seeds as selected from various reports.

There are several factors that vary the effectiveness of peanut seed treatment. The most important of these factors are:

Table 1.—Results of Seed Treatment Tests on Peanuts

Location of test	*Type of seed used*	*Year of test*	*Emergence from Machine-shelled seeds*		*Bibliography reference*
			Untreated	*Treated*	
			Percent	*Percent*	
North Carolina	Runner	'43	54	75	(105)
North Carolina	Runner	'46	50	60-70	(46)
North Carolina	Va. Bunch	'42	39	61	(124)
North Carolina	Spanish	'42	57	72	(124)
Virginia	Runner	'45	66	84	(45)
Virginia	Jumbo	'46	85	96	(46)
South Carolina	Spanish	'45	77	94	(45)
South Carolina	Spanish	'46	54	85	(46)
Georgia	Spanish	'45	53	80	(45)
Alabama	Runner	'46	45	95	(46)
Alabama	Runner	4 yr. ave.	54	73-88	(163)
Alabama	Spanish	'46	43	69	(46)
Alabama	Spanish	4 yr. ave.	50	79	(163)

(a) *Type and quality of seed stocks:* No amount of seed treatment will change poor seed into good seed. Although not recommended, "pegs" (shriveled, under-developed seeds) are still widely used as seed stocks. The comparative effectiveness of seed treatment on plump and shrivėled seeds has been studied (46), and the results indicate that emergence from plump seeds is always considerably higher than that from shriveled seeds. When seeds are stored under conditions detrimental to quality, any subsequent seed treatment will be less effective. Seed treatment, therefore, is not a corrective for improper storage.

(b) *The use of unshelled seed.* Usually there is no appreciable increase in emergence as a result of treatment of unshelled seeds (103, 124, 155, 163). Pre-soaking Spanish peanut pods in water increases the subsequent germination of unshelled seeds (67, 103, 124), but treatment of pre-soaked pods gives no additional increase in germination (103). Germination of pre-soaked unshelled Spanish peanut seeds usually is less than that of treated- machine- or hand-shelled seeds (103).

(c) *Method of shelling.* Injury by machine-shelling provides points of entry for soil fungi, and emergence from untreated hand-shelled seeds is much better than that from untreated machine-shelled seeds. Treating hand-shelled seeds generally increases emergence, but the proportion of increase is not as great as from treatment of machine-shelled seeds. Emergences from treated machine-shelled seeds compare favorably with emergences from untreated hand-shelled seeds (50, 105, 163).

(d) *Material used.* The most apparent factor which can influence the effectiveness of seed treatment is the chemical itself. Numerous fungicides are designed exclusively for seed treatment. Three of these fungicides, Arasan (50 percent tetramethyl thiuramdisulfide), 2 percent Ceresan (2 percent ethyl mercury chloride), and Spergon (98 percent tetrachloroparabenzoquinone), have been tested so frequently that their effectiveness is definitely established. The majority of reports show Arasan and 2 percent Ceresan about equal, with Spergon less effective but still very beneficial (45, 46, 50, 51, 53, 153, 155, 163, 167). Other newly introduced seed fungicides have been tested and some give excellent promise. Extensive testing should soon give definite evaluations for these newer seed fungicides.

(e) *Methods.* The method of applying seed fungicides influences effectiveness of the treatment. A light film of the material on every seed is desired. Higher rates of application do not give additional increases in emergence (103), and over-dosage with mecurial treatments results in abnormal germination and seedling death (67, 163). There are, un-

doubtedly, many cases of apparent ineffectiveness of seed treatment due to poor application of the material used. Slurry treatments have not come into use on peanuts.

(f) *Times of shelling, treatment and planting.* Peanuts shelled and treated up to 3 months or longer before planting produce stands as good as those produced by seeds shelled and treated immediately before planting (51, 103, 163). It appears, therefore, that within reasonable limits the time elapsing between shelling and treatment and subsequent planting does not alter the effectiveness of seed treatment if the seeds are properly stored throughout. Treatments are equally effective if applied at the time of shelling or just before planting.

(g) *Environmental conditions after planting.* Most of the benefits of seed treatment for peanuts appear to arise from prevention of decay of seeds prior to germination (102, 163). Rains which wash off chemicals before germination will decrease the effectiveness of seed treatment (67). Even in comparatively dry soil there will be a gradual dissipation of the chemicals, thus any environmental condition inhibiting or slowing down germination will reduce the effectiveness of treatment.

To summarize: The existing evidence shows that pre-emergence diseases of peanuts are effectively controlled by seed treatment. Factors which influence the effectiveness of seed treatment, however, make the following precautions necessary:

1. Use only high quality seeds which have been stored properly.
2. Use machine-shelled seeds in preference to unshelled seeds.
3. Use a recommended seed fungicide.
4. Follow directions for treatment and avoid injury from over-treatment or failure from under-treatment.
5. Apply chemicals to seeds in a manner which gives even coating of every seed.
6. Choose the most convenient time for shelling and treatment, but keep within reasonable limits.
7. Consider environmental conditions and try to plant under conditions promoting rapid germination.

Post-Emergence Damping-Off

Importance. Typical damping-off causes slight losses every season in the southeastern United States. There are, however, no reports of damping-off as an important disease in any peanut-producing region. Reports of surveys of peanut fields for diseases contain only occasional references

to typical damping-off fungi. When such fungi are mentioned they are given a relatively minor position (97, 123).

Control. Damping-off must be regarded as a minor factor contributing to poor stands of peanuts. The use of treated seeds and close spacing to insure replacements for plants killed by damping-off constitute the only recommended control measures at present. The general prevalence of such practices probably accounts for the infrequency with which damping-off is observed.

Seedling Dry Rots

Importance. Young peanut seedlings are subject to a type of rot distinct from damping-off and known as "dry rot" (63). The fungi apparently associated with most seedling dry rots in southeastern United States are *Sclerotium bataticola* Taub. (the "charcoal rot" organism) and *Rhizoctonia solani* Kuhn. Reports on peanut diseases have shown that these fungi are widespread in the United States (77, 78, 87, 101, 111, 119, 123, 126, 157) and elsewhere (26, 115, 147, 152). In North Carolina each of these organisms accounted for about 35 percent of the total isolations from diseased peanut tissue (101). *S. bataticola* has been called "a major pathological and economic problem" on various crops including peanuts in southern United States (63), and reports on peanuts from India (147, 152) and Palestine (115) have similarly evaluated this organism. There are possibly other types of seedling dry rots as yet not recognized as distinct. For example, an early stage of Fusarium wilt[2] reported from the southeastern United States (74, 92) and other regions (80, 115) may sometimes be confused with seedling dry rots.

Most reports do not distinguish between seedling dry rots and the attacks of the same causal organisms on more mature plants. It has been noted that *S. bataticola* attacks peanuts principally in the seedling stage (63, 152) but some observations may have been of the "ashy stem blight" on mature plants.[3] Observations in southeastern United States tend to indicate that *R. solani* rarely infects mature peanut plants[3] and then generally affects only single branches, but some of these reports may have included attacks on mature plants. On this basis, therefore, seedling dry rots are best regarded as of intermediate importance in relation to development of peanut stands.

Description. Charcoal rot is easily recognized. The first symptoms are greenish-grey watery necrotic areas on stems just at the soil surface.

[2] See page 303 for discussion of *Fusarium* wilt.
[3] See page 305 for discussion of "ashy stem blight," and *R. solani* on mature peanut plants.

As the water-soaked appearance disappears the necrotic areas become a dull, dry brown due to formation of sclerotia of *S. bataticola*. As lesions develop the number of sclerotia increases and the base of the stem looks very much like charcoal. Rarely does the water-soaked appearance persist to the charcoal stage. Usually the entire plant wilts and dies but numerous instances of complete recovery from charcoal rot have been observed. When the lesion remains small, the plant is somewhat stunted and the stem is easily broken by wind or cultivation. The necrotic areas and lesions usually extend below the soil surface for a considerable distance.

Rhizoctonia dry rot of peanut seedlings is typical of the effects of this organism on plants. The first evidence is usually a faint yellowish streak on the stem at the soil line. This streak enlarges, becomes necrotic, and develops into a definite light-brown, dry crack-like lesion. When infection spreads around the succulent stem the top wilts and dies. Sometimes the unwilted tops break off at the lesions. The lesions usually do not extend very far below the soil line. Peanut plants frequently survive seedling infection by *R. solani*.

Organisms and pathogenicity. The parasitism of *Sclerotium bataticola* has been studied with a number of plants. As once summarized (63) it appears that *S. bataticola* is "moderately and variably aggressive. Its invasion is favored by devitalization, characteristic of plants subjected to environmental extremes of continental climates, and wounds or attacks of other organisms. It is adapted to high temperatures." Inoculation tests show that *S. bataticola* can infect and kill peanut seedlings at fairly high temperatures but not at low temperatures (111).

The parasitism of *R. solani* has been established by studies on many crop plants. Inoculation tests show that *R. solani* produces dry-rot of peanut seedlings identical with that found in the field. *R. solani* grows readily from field dry-rotted peanut seedlings in moist chambers though it is sometimes difficult to obtain the organism by the usual methods of isolation.

Although differences in susceptibility of peanuts to infection by *R. solani* have been reported (147), no resistant varieties have been suggested. Twenty peanut varieties have been tested for susceptibility to *S. bataticola* and no resistance was noted though peanuts grown under irrigation and shallow cultivation were attacked more frequently than those grown in dry soil with deep cultivation (147).

Control. Both *S. bataticola* and *R. solani* can be seedborne (41, 48, 147). A high percentage of infection by *R. solani* is sometimes attributed to seed-borne inoculum (147), but it probably is less frequently seed-

borne than is *S. bataticola*. Seed treatment should be effective against most of the seed-borne inoculum. Since these organisms are universally established in peanut soils, seed-borne inoculum may be a minor source of infection. Seed treatment may be effective against a considerable portion of the soil-borne inoculum, particularly in the case of *S. bataticola,* which frequently infects seedlings through cotyledons. Close spacing of seeds to insure replacements is also to be recommended.

Collar Rot[4]

Importance. In the southeastern United States peanuts are subject to a stem and root rot which developed later than damping-off and seedling dry-rots, and features otherwise distinct. The name "collar rot" is proposed for this disease. Apparently such rots have been noted in the southeastern United States for some time (97, 101, 111) and previous reports have indicated that the problem is a complex one (101, 111).

Collar rot was serious in several Georgia counties in 1946 and 1947. In 1946 the entire stand was so depleted in a 10-acre field that replanting was necessary. A similar situation was reported from Texas in 1941 (74). Serious depletions of experimental stands were observed in 1947 in Georgia, and depletions of farmers' fields of runner peanuts were noted in Alabama in 1947 and 1948[5]. A few references in the literature indicate, indirectly, that an early root-rot disease is prevalent in other States (74, 101, 111, 123) and the crown rot of peanuts described from Australia (99, 100) bears many points of resemblance to collar rot.

Description. Peanuts succumb to collar rot from emergence to early flowering. The disease, however, seems most prevalent from 20 to 40 days after planting. When plants are attacked shortly after emergence, hypocotyls are killed and there are black necrotic areas on cotyledons and plumules. In early stages the main axis of plants are wilted with necrotic areas in the region of the cotyledons, but side branches and root systems are unaffected. Frequently a good mat of adventitious roots has been formed just below the cotyledons. Next, the main axis dies and the necrosis spreads downward on the taproot. A few plants recover even after the main axis is dead and the taproot badly rotted. Undoubtedly this recovery is due to good development of adventitious roots. The majority of plants attacked, however, either die or remain stunted. The advanced stage is characterized by dead taproot systems and side branches dying or

[4] Based primarily on observations made in Georgia and on unpublished data of the Georgia Experiment Station.

[5] Observations from unpublished data of the co-author, Coyt Wilson, Alabama Experiment Station.

Table 2.—Fungi Isolated from Peanuts with Collar Rot in Georgia, 1945-1947[6]

Fungus isolated	*Comparative frequency*
Fusarium spp.	Frequent
Diplodia sp.	Frequent
Penicillium spp.	Fairly frequent
Aspergillus spp.	Fairly frequent
Rhizopus sp.	Fairly frequent
Sclerotium bataticola	Fairly frequent
Rhizoctonia solani	Rare
Trichoderma spp.	Rare
Bacteria	Rare

living only when some adventitious roots have developed. In this stage, the main axis and taproot are shredded and held together by a few sound vascular bundles. The mass of dead tissue is usually dark reddish brown and powdery.

Organisms and pathogenicity. The nature of early collar rot suggests a fungous disease, and no evidence has been obtained which would connect insects or grubs directly with the disease. Somewhat detailed isolations of fungi from diseased plants have been made, and typically, a variety of fungi was isolated with no agreement between seasons as to the predominant fungus. Table 2 lists the comparative frequency of isolation of several fungi from diseased plants in Georgia.

Similar results have been reported from North Carolina (101, 111).

Since a number of these fungi have been reported as pathogens on peanuts (table 3), inoculation tests were run for 3 years at the Georgia Ex-

Table 3.—Fungi Ordinarily Considered Saprophytes Reported as Pathogenic for Peanuts

Fungus	*Reported from*	*Pathogenicity tested*	*Pathogenicity proved*	*Bibliography reference*
Diplodia sp.	Southeastern United States	No	—	(119)
	Southeastern United States	Yes	No	(92)
	Southwestern United States	No	—	(79)
	Burma	—	—	(149)
Penicillium spp.	Uganda	—	—	(145)
Aspergillus sp.	East Indies	Yes	Yes	(72)
	Australia	—	—	(99, 100)
Rhizopus sp.	Uganda	—	—	(145)

[6] Unpublished data, Georgia Experiment Station.

periment Station, with fresh isolations of all fungi from collar-rotted peanuts. In two tests one set of plants was wounded by tearing off cotyledons and ripping through stems underneath the soil surface.

With the exception of *R. solani* there was no indication of pathogenicity for any fungi or bacteria. Even the severely wounded plants developed to maturity after inoculation. Most plants inoculated with *R. solani* died, but the necrosis was typical for *R. solani* infection and in no way resembled collar rot as observed in the field. In 1948 with isolates of fungi from collar rot of runner peanuts Wilson[7] found some indication of parasitism for *Diplodia* sp.

From inoculation tests no specific fungus can at present be connected with collar rot of peanuts. There are, however, several possible explanations for the disease, the most likely of which are: (A) The disease is due to a fungus not yet isolated and identified; (B) the disease is due either to *R. solani,* a parasitic *Fusarium* sp., or to a parasitic bacterium and the true pathogen is obscured by a succession of saprophytic fungi; or (C) an involved complex operates in peanut fields in which mechanical injury, chemical injury, insect and nematode injury, and "light" parasitic infection all provide dead tissue in which ordinarily saprophytic fungi thrive and eventually destroy living tissue. A similar complex has been suggested as associated with a root rot of tobacco and small grains (70), and it has been indicated that peanut root rot may, under different conditions, result from a wide variety of fungi (111).

Control. Collar rot has been observed as frequently and to as great an extent in fields planted with treated seeds as in those planted with untreated seeds. There have been instances in which injury from seed treatment has been suspected as a factor in the development of the disease. At present the only recommendations for control are: (A) Use of seed stocks carefully selected to eliminate damaged or broken seeds; (B) use of care in treatment of seeds to avoid injury from seed treatment; (C) close spacing of seeds to insure good stands even if some plants are killed by collar rot.

DISEASES OF THE GROWING SEASON

Cercospora Leafspot

Importance. Because of frequency of occurrence *Cercospora* leafspot is generally regarded as one of the most important diseases, or perhaps the most important disease of peanuts. Although it has received more at-

[7] Unpublished data, Alabama Experiment Station.

tention than any other disease of peanuts in the United States, there is little agreement as to its relative destructiveness.

Obviously the defoliation greatly decreases the value of the vines for hay, but as indicated by Miller (94) there are observers who feel that leafspot does not result in appreciable reduction in yield of nuts. The majority of observers, however, maintain that considerable loss in yield of nuts results from the disease.

The best estimate of importance of peanut leafspot may be obtained from results of studies on control. In Virginia 30 tests showed average yields about 500 pounds per acre less in untreated fields than in fields in which leafspot had been decreased by control measures (94). This indicated a loss in yield of about 20 percent from leaf-spot infection. Interpreting results of extensive tests in Georgia similarly (172) the nut-yield loss from leafspot is indicated as from 20 to 25 percent.

Description. Two fairly distinct types of necrotic spotting are recognized as common on peanuts in the southeastern United States, and each has been connected with a specific *Cercospora* sp. (68, 171). The existence of two species of *Cercospora* associated with peanut leafspot was clarified by Woodroof in 1932 (171). The effects produced by these organisms, however, are still regarded as only one disease. Control measures seem equally effective on both organisms. Peanut-breeding programs, however, may produce varieties resistant to only one of the pathogens (61), in which case it may be necessary to divide "peanut leafspot" into two diseases.

Spotting associated with *Cercospora arachidicola* Hori (*Mycosphaerella arachidicola* Jenkins) appears earlier and becomes epiphytotic earlier than does that associated with *C. personata* (B. and C.) E. and E. (*M. berkeleyii* Jenkins). It seems logical, therefore, to designate them "early leafspot" and "late leafspot." There is a period of overlapping, however, and frequently both types of spotting are found on the same plant (171).

In the initial stages the two types of spotting are indistinguishable (68). Spots appear as slightly pale or blanched-like areas and a breakdown of the lower epidermis is evident. The spots develop rapidly and become distinctly yellow on the upper surface of the leaflet. With this a necrosis develops from the center of the lesion, or the entire lesion may become necrotic at one time.

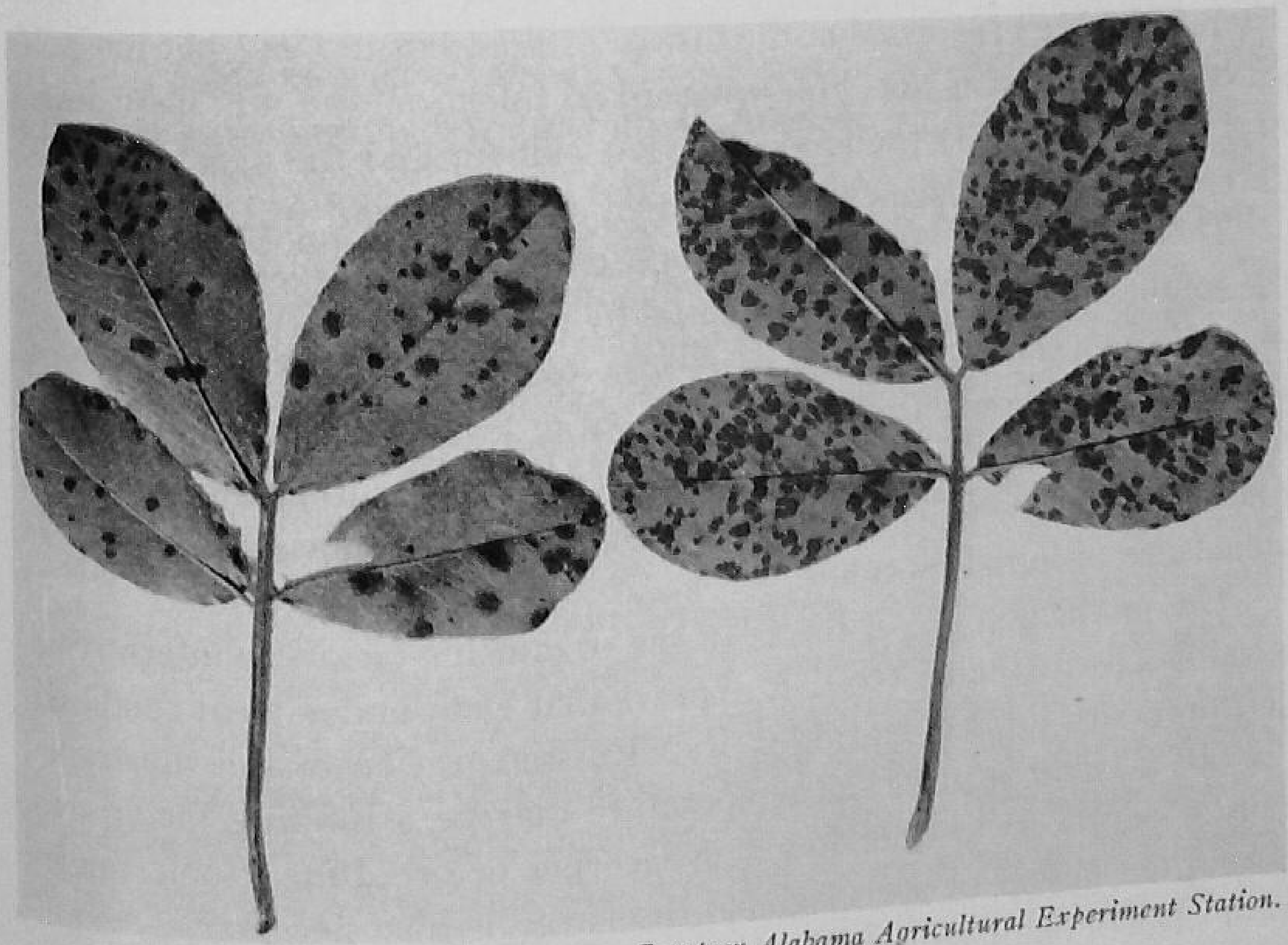
Later stages in necrosis serve to distinguish between the two leafspots (68). Early leafspot is characterized by a yellow halo of variable width, while halos are found only with more mature spots of the late type.

At maturity early leafspots are reddish-brown to black, and lighter brown to tan with less distinct halos on the lower surface. Late leafspots are soon very dark brown to almost black on both surfaces.

Cushions of conidiophores are formed at first only on the upper surface in early leafspot, but sometimes form on the lower surfaces of older spots. In late leafspot, however, conidiophores are almost always confined to the lower leaf surfaces, and the cushions of tufts usually are in plainly visible concentric circles. When the conidiophore cushion of late leafspot becomes amphigenous with age, this concentric marking remains plainly evident (68).

Both leafspots are distinctly necrotic at maturity. The spots are circular, or irregular, and often coalescing. Sizes range from 1 mm. to over 1 cm. in diameter (68). Spots on stems, petioles, pegs and pods are similar, but more frequently are irregular or eliptical in shape. In early leafspot the petioles and stem lesions develop later in the season than do those on the leaves (171). These symptoms are shown in figure 1.

Apparently control measures so effectively prevent premature leaf shedding (68, 171) that few observations have been made on defoliation



Courtesy Alabama Agricultural Experiment Station.

Figure 1.—Cercospora leafspot on leaves of runner peanuts. The spots with the halos on the leaf at the left are old lesions caused by *Cercospora arachidicola*. The dark spots on the leaf at the right are young lesions caused by *Cercospora personata*.

effects. The interrelationships between time of infection, severity of infection, beginning of defoliation, and severity of defoliation have not been extensively studied. In Georgia, leafspot appears sometimes in June on peanuts planted in late April (172), and without control spotting increases rapidly during July so that defoliation is noticeable by August. A close relationship is observed to exist between the amount of leaf spotting and the amount of defoliation (94).

Comparative studies (68, 171) have shown that late leafspot usually appears 3 to 4 weeks later than early leafspot.

Organisms and pathogenicity. Woodroof (171) has clarified the synonomy and nomenclature of the conidial stages of the peanut leafspot organism. Her studies established *Cercospora arachidicola* Hori as the correct name for the early leaf-spot organism, and *C. personata* (B. and C.) E. and E. as the correct name for the late leafspot organism. Jenkins (68) studied the development of both organisms and connected them with *Mycosphaerella* perithecial stages which were found to develop only on overwintered material.

The pathogenicity of both organisms has been proven (68). The first infection is from ascospores formed on overwintered peanut debris. There have been reports that the disease is seed-borne (94) but most observers feel that it is not. Following initial infection and an "incubation" of 2 to 3 weeks (68) the lesions become evident and the organisms produce conidia in abundance. These conidia then spread infection rapidly.

There is a leafspot of the common coffee weed (*Cassia tora* L.) of the southeastern United States caused by a *Cercospora* sp., but attempts at cross inoculation of this *Cercospora* sp. with peanuts have failed[8]. Possibly other weeds are hosts of the peanut leaf-spot organism and thus may serve as additional sources of ascospores for initial infection. As a rule, however, there is more than enough peanut debris to provide an abundance of initial inoculum.

The production of perithecia of the organisms on overwintering material has been studied (68). It appears that even under ideal conditions perithecia are formed sparingly. Rapid disintegration of the substratum may be a factor in this, and temperature may be a limiting factor since mature perithecia are not found in Georgia before June. Some rainfall during the period of spermagonial discharge is also necessary. Asci almost always mature gradually so that ascospores are discharged over a considerable period of time. Initial infections usually are scattered in the southeastern United States (68), but peanut fields rarely, if ever, escape

[8] Unpublished results, Georgia Experiment Station.

infection. Small spots of initial infection serve as the starting point from which secondary infection spreads over almost unlimited areas.

Conidia are primarily windborne (94) and other means of dissemination are of little significance. Under ideal conditions conidia germinate within 3 to 8 hours (68). The conidia do not germinate if completely covered by water, or if there is insufficient moisture. Infection takes place through either surface of the leaflet, but most infection probably is through the lower surfaces since they are not subject to rapid dessication.

Penetration of the germ tube is through epidermis or stomata. *Cercospora arachidicola* has intercellular mycelium but no haustoria. Host cells die rapidly in advance of the mycelium, and the hyphae penetrate the dead cells. Mycelium of *Cercospora personata* leafspot organism remains intercellular with branched or botryose haustoria which may be found in apparently normal cells.

The early leaf-spot organism develops consistently but the late leaf-spot organism is sporadic, being widespread some years, and again rarely found or entirely missing. It appears that, when occurring, the late leaf-spot organism causes a more rapid defoliation (68, 171). The regular occurrence of early leafspot and harvesting of many peanuts before late leafspot reaches epiphytotic proportions indicate that in lower southeastern United States early leafspot is more destructive. In this region early leafspot usually becomes epiphytotic in August; late leafspot sometime in September (68).

Factors influencing the severity and spread of infection by leaf-spot organism have been studied and discussed (94). Various fertilizer programs have no apparent effect on the disease. Age of plants, rate of early growth, method of weed control, and frequency of rainfall appear to be influencing factors. Infection is usually more severe on peanuts following peanuts every year or every other year than when 3-year rotations are practiced.

Control. Field sanitation can offer no great hope for control of peanut leafspot. Resistance has been reported sporadically, but at present no definite resistance exists in any standard variety of peanuts. The possibilities along this line have been discussed by Higgins (61, 62) who noted an apparently independent inheritance of resistance to the two types of leaf spotting. Recently, Miller has reported the existence of physiological races within each species (93) which may complicate breeding programs. Resistant varieties may result from some of the current breeding programs, but present-day control measures must center in preventing spread of infection.

As shown by studies in Georgia (172), the most logical means of preventing spread of infection, is the application of fungicides which kill conidia on leaflets before they germinate and penetrate leaf tissue. Tests in Virginia (94) have indicated that plants so protected lose a lower percentage of nuts in the soil before digging, lose a lower percentage of nuts at digging, and have a greater total yield. Similar results, particularly in regard to total yield, have been obtained in Alabama (165).

Results suggesting that fungicidal applications sometimes influence the number of nuts left on the vine rather than total yield have been obtained in Florida. When the nuts left in the soil were added to the harvested yield there was no appreciable difference in total yields between control and check plots (20). However, this publication cited the unpublished results of other control tests in Florida carried on over a period of 5 years and these other tests indicated a 15 to 20 percent increase in yield of harvested nuts. Also, the weather of the particular year in which these experiments were made was conducive to leafspot so that no correlation was evident between treatment and leaf-spot control.

Various fungicides have been tested as dusts and sprays (94, 165, 172). Pending further testing of newer fungicides it seems that either sulfur or 10-90 copper-sulfur with the mixture containing the equivalent of about 3.5 percent metallic copper are to be recommended as dusting materials. Spraying with Bordeaux (6-2-100) gives satisfactory control but is no better than dusting.

The following general recommendations for procedure in dusting for leafspot control have been modified from Woodroof et al. (172) after checking for agreement with Miller (94) and with Wilson and Arant (165):

1. Practice rotations of fields to peanuts at 3-year intervals. Maintain vigor of plants by fertilizer, cultivation, etc.

2. Dust with conditioned dusting sulfur (at least 93 percent through 325 mesh) or copper-sulfur 10-90 (34 percent basic copper sulfate 10 parts, dusting sulfur 90 parts).

3. Begin dusting about 90 days after planting.

4. Apply dust every 10 to 14 days. If rain occurs within 24 hours after first dust, repeat after 7 days. If rain occurs within 12 hours after later dusts, repeat dusting as soon as possible. Continue dusting to within 14 days of harvest. Three to five applications usually are required.

5. The size of the vines determines to a considerable extent the amount of material required for coverage; 12 to 15 pounds per acre of

material will do for first dusting, 15 to 20 pounds per acre for later dustings. A visible coating of dust should cover the stems and both surfaces of leaflets.

6. Use any tractor or power row-crop duster which will permit directing some dust at ground to insure bounce to cover lower surface of leaflets. A short canvas hood should extend to lower edge of nozzles in front and drag the top of the plants behind. This hood permits dusting any time except when wind velocities are very high, and insures better coverage of the plants.

SCLEROTIUM BLIGHT OR SOUTHERN ROOT ROT

Sclerotium rolfsii Sacc. causes three distinct diseases of peanuts: (A) Root and crown rot of plants in intermediate and advanced stages of growth; (B) soil-rot of pegs (gynophores) and pods of fruits approaching maturity; (C) blue-black discoloration ("blue-damage") of the seeds of Spanish-type peanuts.

The present discussion is concerned only with the root and crown rot. This is the most spectacular disease of the Spanish peanut belt of the southeastern United States and, consequently, is known by a variety of names. The more commonly encountered names are "southern root rot," "southern blight," "blight," "white mold," (sometimes "blue mold") and, in other regions, "crown rot," "foot rot" or "*Sclerotium* wilt." All of these names indicate some recognition that the causal organism is a general pathogen and not specific to peanuts. The inclusion of "southern" in the name of the disease indicates that the disease is usually confined to warmer regions. Of the names given the disease "*Sclerotium* blight" seems preferable since the disease is not confined to peanuts, and is not localized in the "South".

Importance. In the earlier days of peanut production in the United States attacks of *Sclerotium rolfsii* upon the crown region received considerable attention (2, 88, 150), but for a later period of about 15 to 20 years this disease attracted attention only in the Spanish peanut region of Georgia (91, 92).

Sclerotium rolfsii has been reported as responsible for deaths of plants approaching 50 percent of the stand in some instances in North Carolina (113) while another report listed *Sclerotium* blight as the cause of death of as many as 10 percent of the plants (13). Reports from Texas indicate considerable loss from the disease every year (1, 149). Other reports listed losses from *S. rolfsii* as slight in Mississippi (108) and Virginia (150). Some plant pathologists recognize the importance of the disease

but feel that *S. rolfsii* may be a secondary invader and, therefore, are not willing to attribute the losses to this organism.

Sclerotium rolfsii seldom kills the entire plant of runner peanuts since portions away from the point of attack are usually supported by the adventitious root system. Therefore, the disease is not as spectacular on runner peanuts as on bunch peanuts. There are three general views as to the importance of *S. rolfsii* on runner peanuts: (A) Runner peanuts are sometimes regarded as somewhat resistant to *S. rolfsii;* (B) *S. rolfsii* is sometimes called an important peg-rotting organism, but an unimportant blight-producing organism on runner peanuts; (C) finally *S. rolfsii* is frequently regarded as an important blight-producer on runner peanuts.

Thus, there is a divergence of opinion as to the importance of this disease in the United States. This undoubtedly results largely from a combination of three factors: (A) The newness of peanuts as a commercial crop in some areas; (B) a tendency to question the parasitism of *Sclerotium rolfsii* (12, 101); (C) the somewhat different end response to attacks of *S. rolfsii* exhibited by bunch peanuts as compared with runner peanuts.

Sclerotium blight is well known in other peanut-producing regions. In South Africa, where it is known as "foot rot," it has been reported as jeopardizing the future of peanut growing (22). In the Philippines, programs have been initiated, attempting to discover varietal resistance (115). Losses reported for this disease in Peru vary from light to heavy (40). A disease has been reported from Rumania (200) and Bulgaria (34) that appears to be *Sclerotium* blight. It is a matter of conjecture whether or not the disease is important in such areas as Australia, although its importance in Ceylon has been questioned (17).

Description. The two most distinctive characteristics of *Sclerotium* blight are death of above-ground portions of plants and a mat of white fungus hyphae and tannish-red sclerotia around stems at the soil surface. The entire plant or only one or two branches may be killed (22, 92, 150). When only branches are attacked on bunch peanuts the unattacked portion may remain healthy and vigorous, or it may be stunted and yellowish and have few or no nuts at maturity. The unattacked portions of runner peanut plants usually remain vigorous, although nut production may be poor.

The center of infection is at the soil surface, and death of aboveground portions of plants is due to severance of the water-conducting tissue of the roots and stems. The leaves usually wilt slowly, reviving at night so that wilting is most evident in the middle or later part of the day. The leaves turn brown gradually, and several days may elapse before the

branch or plant appears completely dead. Usually the dead leaves remain on the branch.

Death of above-ground portions of the plant sometimes takes place very rapidly, particularly in extremely hot weather. When death is extremely rapid, the necrosis may develop as a blackening rather than as a browning. In such cases preliminary wilting does not occur or is evident for a very short time. Under such conditions *Sclerotium* blight does not show the characteristics of a wilt (92).

From South Africa (23) it has been reported that plants infected by *Sclerotium rolfsii* may be conspicuously robust and healthy due to incomplete disintegration of the vascular bundles with the xylem remaining functional. Thus water and minerals move upward, but downward movement of foods is inhibited and there is a surplus of food for top growth.

Organism and pathogenicity. The organism associated with *Sclerotium* blight of peanuts is *Sclerotium rolfsii* Sacc. This sclerotial fungus has a basidial "perfect" stage which is either a *Corticium* sp. or a *Pellicularia* sp. (160). Other species of *Sclerotium* have been reported on peanuts (17, 34, 120) but it seems probable that these are merely forms of *Sclerotium rolfsii.*

The basidial stage is very rarely found in nature and pathologists have continued the use of the name of the sclerotial stage. The fungus is usually easily identified by the abundance of tannish-red sclerotia which vary in size from .5 to 2 or 3 mm. or larger. Size of sclerotia apparently depends upon age, physiological condition, or strain of the organism. The sclerotia are generally spherical in shape, but may be flattened or otherwise misshapen.

Sclerotium rolfsii frequently produces mycelium on the soil surface or on decaying organic matter before sclerotia are evident. This mycelium is a dense hyphal mat which fans out from a central point of origin. The organism may be identified by microscopic examination since the hyphae have double clamp connections.

The length of the dormant period of the sclerotia of *Sclerotium rolfsii* is governed by food supply and temperature (60). Sclerotia can remain viable for a considerable period of time. In the southeastern United States viable sclerotia may be found in the soil throughout the year and serve as a means of spreading the fungus through or between fields.

Greenhouse experiments indicate a relationship between organic-matter content of soil and parasitism of *S. rolfsii* on peanuts (54). In peanut fields, however, the spots of high organic-matter content are not necessarily the spots of maximum death from *Sclerotium* blight.

Sclerotium rolfsii is typically a "warm-region" fungus. Its temperature

relations seem to be the limiting factor in its geographical distribution (60). In warmer regions it attacks a wide variety of plants, including common weeds. The organism has been reported killing almost all cultivated plants grown in temperate and subtropical zones, including seedlings of forest trees. Members of the grass family are regarded as somewhat less susceptible, and certain plants such as some varieties of cowpeas (73) are reported as appearing to be resistant.

The general parasitism of *S. rolfsii* has been thoroughly investigated. It seems definitely established that it is a potent parasite on a wide variety of plants and that its omnivorousness is due to a peculiar type of parasitism (60). The fungus is primarily active in the soil and at the soil surface (54), and a mat of hyphae is formed over the basal portion of any plants growing in spots of the fungus. The fungus clings to the epidermis of plants by holdfasts, and the hyphae secrete considerable quantities of oxalic acid. Cells of the plant are killed by this oxalic acid in advance of the fungus hyphae (60). The hyphae apparently do not penetrate living cells, but will grow into cells killed by oxalic acid. Thus, any plant with an epidermis permeable to oxalic acid will be killed by contact with the fungus.

The factors affecting the parasitism of *Sclerotium rolfsii,* are centered in the physiological activities of the fungus and not in the reactions of the host. That the physiology of this fungus in the soil is variable is indicated by its peculiar behavior in peanut fields. Infections are spotted and these spots do not appear in the same place in the field from year to year. They do not appear to be related to soil differences, spots of high organic content, spots of variable drainage, or any other easily discernible factor. In a given season, there seems to be no tendency for the fungus to spread out of these spots.

It has been shown that *Sclerotium rolfsii* can be seedborne in peanuts (41, 54, 64, 72, 111, 149), but the possibility of infection from this source is greatly overshadowed by the possibility of infection from the soil (142).

Control. At present there seems no basis for making positive recommendations for control of *Sclerotium* blight on peanuts or other crops. Although there have been occasional reports of apparent resistance in progeny resulting from peanut breeding and selection programs (54, 116), the nature of the attack of *Sclerotium rolfsii* suggests that resistant varieties of peanuts are improbable. There is no reason to expect differences in permeability of the epidermis to oxalic acid. There has been a persistent contention that runner peanuts are less suceptible to *Sclero-*

tium blight than are bunch types (22, 92), but many observers feel that this is actually a difference in response to attack resulting from a difference in habit.

In the United States it is believed that attacks of *Sclerotium rolfsii* on peanuts are less severe in heavy (92) or poorly aerated land (54). In South Africa it is indicated that well-drained friable soils should be used for peanut culture to reduce losses from *Sclerotium* blight (64), although the disease has been reported from this region as equally severe on all soil types (22). In Georgia, *Sclerotium rolfsii* seems less severe on heavier soils, but these soils are not particularly adapted to peanut culture and are usually avoided by peanut growers. Deep plowing, recommended in South Africa for control of *Sclerotium* blight (22), has not been thoroughly tested in the United States.

The number of susceptible crops suggests that it is impractical to eradicate *Sclerotium* blight by crop rotation (92). It is reported from North Carolina that there appears to be no relationship between previous crops and prevalence of the disease on peanuts (13). In Virginia, however, an apparent correlation has been observed (150). In South Africa it is suggested that peanut fields may be cleared of the fungus by following peanuts with a grass crop for 2 years, then another legume such as soybeans the third year (22). Also, in South Africa it is thought that virgin soils should be planted to a nonsusceptible crop for a year or two before planting to peanuts (22). In Texas it is recommended that infested peanut fields be replanted to the apparently resistant varieties of cowpeas (72). In Georgia a preliminary survey indicated that *Sclerotium* blight is more severe on peanuts following peanuts, cotton or lupine than on peanuts following corn or small grain (52).

Some soil treatments have been tested for control of *Sclerotium* blight of peanuts. One test reported no results (92). A report from North Carolina in 1938 indicated beneficial results from some inorganic elements added to fertilizer and from sulfur and lime applications (111). In 1941, also from North Carolina, some control was reported from heavy applications of copper and sulfur to the surface of the soil in peanut rows during July and August (101).

At present, therefore, only general recommendations for control of *Sclerotium* blight can be made. These include:

A. Plant good, carefully treated seeds to insure proper stand establishment and initial vigor.

B. Plant seeds thickly to insure good stands.

C. Maintain vigor by dusting for leafspot.

D. Harvest peanuts as soon as practicable from fields in which *Sclerotium* blight is bad.

E. Abandon from peanut culture for several years fields in which *Sclerotium* blight appears exceptionally severe.

F. Follow a strict rotation policy in which grass crops play a prominent role in all peanut fields.

DISEASES OF MATURATION—SOIL ROTS OF FRUITS (PEGS AND PODS)

In the following discussion the gynophore or fruit stalk is called the "peg" and considered a part of the peanut fruit. The shell and seed portion of the fruit is called the "nut" or "pod." The peanut fruit is usually called a "peanut" or a "nut." The peanut differs from most legumes in that the fruit matures underground and in that the gynophore is considerably elongated. This elongated fruit stalk is usually called the "peg," although shriveled, under-developed peanut seeds are also called "pegs" in some sections.

Importance. By harvesting time in the southeastern United States many nuts are partially or completely rotted and many seeds of Spanish peanuts have sprouted in the pod. Many nuts pull off the vines and are left in the soil. These losses result either from rots or from the pegs becoming mature, brittle or otherwise weakened before harvest. These pathological and physiological factors are undesirable aspects of the maturation process and are "maturation diseases."

Several surveys have noted these maturation diseases as important in peanut culture (11, 95, 96, 119, 125, 127) and a few figures or estimates of importance are available. In Virginia and North Carolina in 1931 (95) up to 10 percent of the marketed nuts were rotted or "pickouts." The same year losses due to soil rots were estimated as: Virginia 5 to 10 percent; North Carolina 5 percent average; South Carolina 5 percent average on most soils; Georgia 10 to 30 percent in most localities and up to 50 percent in others; Alabama from 1 to 30 percent in various localities (98). Surveys in 1943 estimated losses from maturation diseases as: Virginia 30 percent in one section and from 5 to 50 percent in all sections (150); North Carolina a loss of $20 to $50 per acre; Alabama an estimated average of 12 to 15 percent (139).

Description. Following pollination the peduncle (gynophore) of the pistil elongates rapidly and becomes the peg. This forces the ovulary into the soil where most development takes place. Usually at maturity all of the nut and most or all of the peg are in the soil. The peanut fruit matures, then, under conditions conducive to attacks of microorganisms.

If fungi infect the peg it may decay the pod in the soil, or it is weakened so that the pod is pulled-off in the soil or otherwise lost in harvesting. Attacks upon the nut result in discoloration or decay of the shells and eventually in discoloration and partial or complete decay of the seeds. This fungous invasion of the maturing peanut fruit may be facilitated by insect or nematode action (113, 161) but it is not dependent upon this.

Preharvest sprouting of seeds is frequent in Spanish peanuts and certain peanut varieties other than the common runner that do not require an after-ripening period before germination. Large numbers of sprouted seeds are found on Spanish peanut vines when the pegs show evidence of considerable fungous infection. This indicates that fungi may be responsible for considerable preharvest sprouting of seeds. Probably infection of the peg stops the movement of water and food materials resulting in premature ripening and abnormally early germination.

Infection of the peg, however, is the only one of the causes of breaking of pegs at harvest (139). At maturity all vegetative parts of the plant are brittle. Premature leaf shedding from disease or insect attacks also hastens vegetative maturity and the pegs become brittle abnormally early.

Organisms. Peg breaking or seed damage may result from action of a number of common soil fungi. Fungi isolated from soil-rotted peanuts (13, 96, 109, 113, 118) and from peanut seed stocks (41, 44) show that a variety of saprophytic and parasitic fungi is associated with pod rots. Nematodes have also been reported as a cause of damage to peanut pods (113).

Somewhat detailed isolations (161) showed about one-half of the rotted fruits were infected with miscellaneous molds (*Penicillia, Aspergilli, Rhizopus* spp., etc.). The remainder were infected with *Sclerotium rolfsii, S. bataticola, Diplodia* sp., *Rhizoctonia* spp., or *Fusaria. S. rolfsii* was reported several years ago (168) as a cause of peanut fruit rots and in 1931 (91, 98) and 1943 (150) it was reported as the predominant organism apparently associated with soil rots of peanuts. The variety of fungi isolated from field-rotted nuts (161) suggests that *S. rolfsii* is usually not the most important organism, but rather is only one of several important organisms.

Early defoliation of plants also causes peg breaking. Thus any disease or insect injury resulting in leaf shedding will increase losses due to peg rot.

Some cases of peg breaking can only be blamed on over-maturity of the pegs at harvest. This is a result of miscalculations and cannot be called a disease.

Control. Since maturation diseases are affected by several factors,

control measures consist mainly of management practices that increase the vigor of the plant and prevent premature defoliation. Control of leaf-spot and leaf insects tends to keep the pegs from becoming brittle prematurely and decreases invasion of pegs by saprophytic fungi and the natural breaking of pegs at harvest. Apparently fertilizer applications may sometimes result in more peg breaking at harvest (57). There have been suggestions of varietal differences in peg breaking at harvest (82), but more evidence is needed before definite conclusions can be drawn.

Pending further study the following strictly tentative recommendations for control of maturation diseases are suggested:

A. Keep plants as vigorous as possible up to harvest.
B. Follow a dusting program for control of leaf diseases and insects.
C. Avoid planting peanuts on fields where *Sclerotium* blight has been severe on peanuts in the past.
D. Avoid planting peanuts on fields where nut rots, peg breaking, or seed sprouting has been severe in the past.
E. Make frequent checks on pegs and pods toward the end of the growing season. If pegs or pods are beginning to rot, harvest the crop immediately. If no rotting is evident, harvest the crop before the pegs become brittle from natural maturity.

DISEASES OF CURING

Since the peanut pod develops in soil it is subject to attack by a host of soil fungi. This invasion begins early (161), and fungi are associated with the fruit after peanuts are cured (44, 48, 114, 162). If this invasion were confined to the shell, it would be unimportant, but fungi frequently grow through the shell and around or into the seeds. This results in damage to the seeds.

When peanut vines and nuts are stacked, piled or windrowed for curing, the environment becomes ideal for growth of fungi (49). During curing, then, there is an excellent opportunity for development of damage to seeds which were undamaged at digging. Concealed damage and blue damage are two distinct types of seed damage that develop primarily during the curing process (48, 49, 162).

CONCEALED DAMAGE

Importance. Concealed damage—sometimes called "hidden damage" —is a type of seed damage not visible until the seed is broken open. Its nature, therefore, insures it some importance for its "nuisance value." It

is found most frequently in certain varieties of peanuts, but the possibility of its presence in any variety makes necessary elaborate and time-consuming sampling procedures. Since the price that the grower receives for peanuts is determined by the shelling percentage and by the amount of damage in the sample, concealed damage often becomes very important. It was estimated that in 1945 farmers in Alabama alone lost 2½ million dollars from penalties imposed because of damage (162).

The importance of concealed damage in any given locality depends largely upon the variety of peanuts grown. Concealed damage is sometimes found in Spanish peanuts (114, 162) but it is rarely of any consequence (48, 162), so that in areas where Spanish is the predominant variety concealed damage is of slight concern. Farmers in other areas (162), however, find concealed damage very important. A newer variety, Dixie runner (30), appears to be less susceptible than the common southeastern runner (30, 52, 82, 156, 162). Concealed damage has never been considered important in Virginia-type peanuts.

A preliminary study of varietal susceptibility has been made in Georgia (52). From this and other observations the following tentative grouping of peanut varieties according to apparent susceptibility to concealed damage is offered:

Very susceptible
- Southeastern runner (Alabama, Georgia, or Florida runner, etc.)

Susceptible
- Georgia bunch
- North Carolina bunch

Uncertain
- Jumbos
- Valencias, etc.

Intermediate
- Dixie runner

Somewhat resistant
- Virginia runner
- Virginia bunch

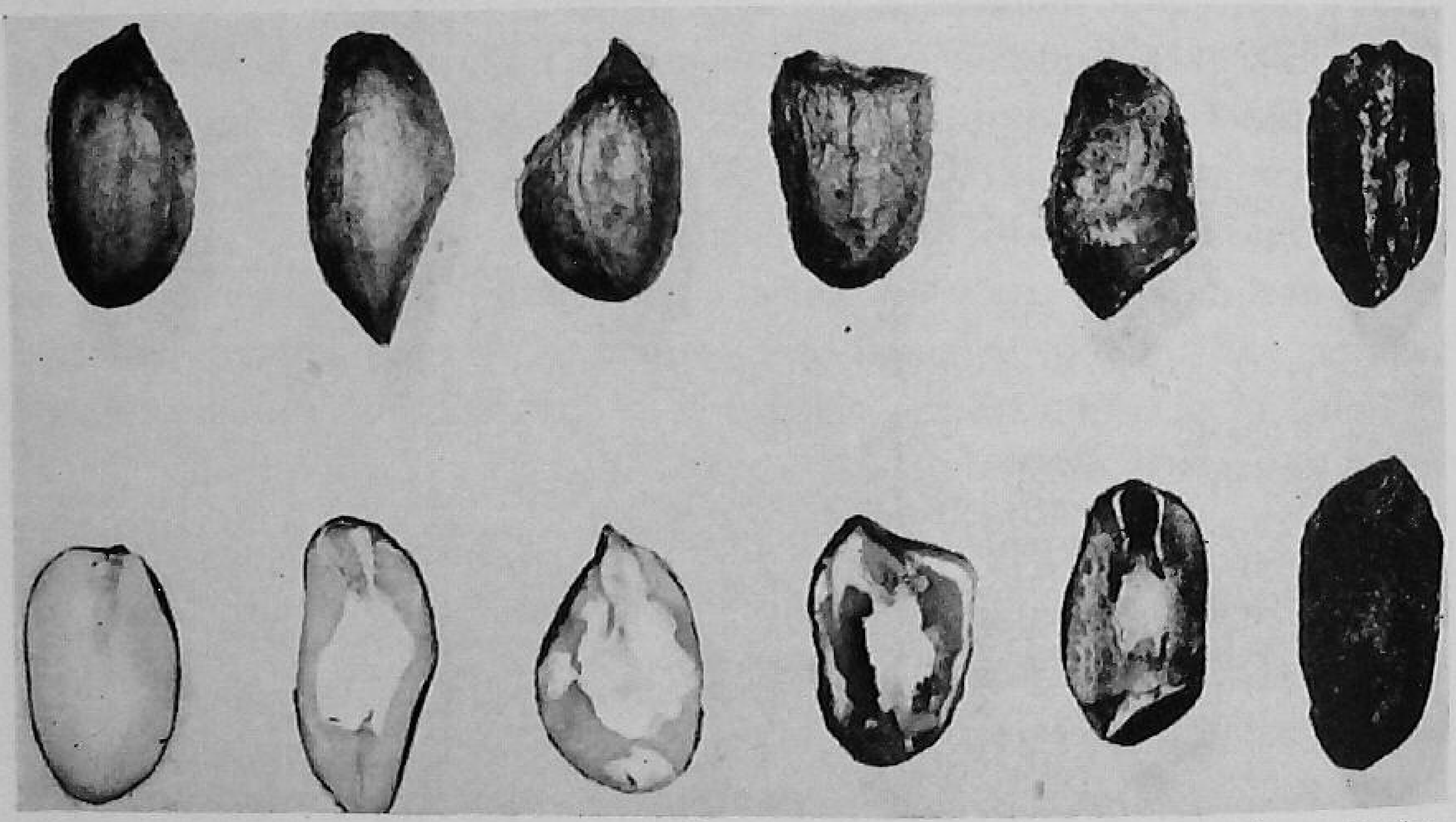
Resistant
- Spanish

Preliminary data indicate that some unreleased hybrids and selections of the large-seeded type are more resistant to concealed damage than is Dixie runner (52). Even though apparent resistance to the disease is not yet fully explained there is hope that resistant large-seeded varieties will replace the susceptible types.

Description. Concealed damage is seed decay beginning at the interface between cotyledons and developing outward. The first evidence is a slight discoloration of this interface, and this is usually followed by defi-

nite yellowing. With this yellowing a mycelial mat is usually found between the cotyledons but sometimes this mat is found before discoloration of the cotyledons is evident. As the disease progresses, the mycelial mat and cotyledons become darker and eventually the entire seed becomes black or dark purple. The decay may gradually become apparent from the exterior of the seeds so that the seed coat becomes shriveled, its color fades, the seed appears oily, and feels soft (48, 162). Even in this stage, however, the seed appears normal to all but the most experienced observers. These symptoms are shown in figure 2.

This semi-detectable stage is soon succeeded by a stage in which the dark decomposition products are visible from the exterior. At this stage



Courtesy Alabama Agricultural Experiment Station

Figure 2.—Concealed damage in runner peanuts. Outside and inside views of healthy seed at left and damaged seed at the right. The damage on the seed at the extreme right is no longer concealed.

the damage is no longer concealed, but is visible (48, 162). After the seed are completely decayed it is not possible to determine whether the infection spread from between the cotyledons or developed inward from the surface. The important factor is the period in concealed damage during which seeds with partially decayed cotyledons appear to be perfectly sound seeds.

Seeds with concealed damage have a strong, rancid taste (162). This is the primary danger since a few of these seed taint an entire product. In processing peanuts these seed are difficult to avoid since bitterness develops before external symptoms. In addition to rancidity there is an increase in free fatty acids (162).

Two other types of interior damage can be confused with concealed damage. In one type the interior of the cotyledons is shrunken, cracked and discolored reddish-brown. Apparently this is a physiological trouble; no fungi have been isolated from these cotyledons and there is no rancidity. It is rare (162) but has been found in several varieties and is found more frequently in Virginia peanuts than is concealed damage. The other type, a soft rot apparently beginning in the "germ," is rarely noted (162).

Organisms and pathogenicity. Mycelial mats between the cotyledons of concealed damaged seeds suggest that a fungus is concerned, and the disease has been reproduced by inoculations with fungi isolated from seeds with concealed damage (48).

The lists of fungi isolated from concealed damaged seed in Georgia (48) and Alabama (162) are strikingly similar. *Diplodia* sp.[9] made up almost 90 percent of the isolations in both cases. Miscellaneous saprophytes—*Fusaria, Aspergilli, Penicilli, Sclerotium bataticola,* etc.—accounted for the bulk of the remainder. Parasitic forms such as *Rhizoctonia solani* and *Sclerotium rolfsii* were rare. *S. bataticola,* however, was isolated more frequently in Georgia (48) than in Alabama (162).

Inoculation tests have shown that *Diplodia* sp. can produce concealed damage (48). Therefore, it is regarded as the predominant organism involved. Concealed damage was also reproduced by inoculation with *Sclerotium bataticola* and perhaps one or two other fungi (48). Thus, while most concealed damage is due to *Diplodia* sp., other fungi can and sometimes do cause the damage. It has been suggested, however, that *Diplodia* sp. is the pathogen and other fungi are secondary invaders (162).

Concealed damage usually results from infection which takes place before peanuts are dug (162). The same fungi may be isolated from sound seeds and from concealed damaged seeds (48). Concealed damage is found when peanuts are bought on the market but the disease is rare in freshly dug peanuts and then is found only in the early stage. It is apparent, therefore, that concealed damage develops primarily during the curing season.

The causal fungus invades the intercotyledonary space through the shell and the placenta (48). Thereafter growth of the fungus is conditioned by moisture content of the seed. The damage develops most rapidly in green peanuts with moisture contents 15 to 35 percent (162). Above

[9] The taxonomy of the form genus *Diplodia* is extremely confused. The fungus isolated from concealed damaged seeds could be put in any of several species including three species originally described from peanuts. The present report prefers to regard it as "*Diplodia* sp." until it has been studied further.

and below these moistures, concealed damage develops slowly, with little development below 10 percent. There seems to be no relationship between soil type or fertilizer practices and development of concealed damage. It may be more prevalent, however, when fields are cropped continuously to peanuts.

Control. Moisture content being closely related to development of concealed damage, control measures are centered in attempts at rapid drying of seeds. Since artificial curing with dry air is still in the experimental stage, control of concealed damage at present is dependent upon some variation of field curing that hastens the removal of moisture.

The safest method of field curing peanuts is stacking rather than windrowing or piling in "cocks" (166). Preliminary studies in Florida (21) have shown no relation between method of stacking and concealed damage, but similar studies in Georgia (52) have indicated that significantly less concealed damage develops when plants are stacked wilted (not brittle) than that which develops when plants are stacked "green" or unwilted.

BLUE DAMAGE[10]

Importance. Spanish peanuts reaching the market are frequently graded down because of a prominent blue-black discoloration of many seeds. In some years this discoloration is not troublesome, but in other years peanut shellers have reported losses up to 25 percent from this disease. Sometimes entire lots are rejected by peanut brokers because of this discoloration.

Description. Usually when blue damage is found in a seed lot, a large proportion of the seeds is conspicuously affected, though sometimes only very few seeds are damaged. The discoloration may occur in such an inconspicuous form and on so few seeds that it is easily overlooked.

This discoloration varies through several shades of blue-black. One spot may be of several shades, or different spots on the same seed may be of different shades. Sometimes the discoloration is a streak following either veins of the seed coat or the suture between cotyledons. The spots vary in size. The smallest are about 2 mm. in size and of a distinct "bull's eye" type with centers bleached, slightly darker, or the natural color of the seed coat. Larger spots are irregular in shape with no evident center. All possible variations can be found in a single lot of discolored seeds.

Spanish peanut lots containing blue-damaged seeds generally have

[10] This section is a condensation of the report by Garren, Higgins and Futral (49), the only published work on this disease to date.

more discolored or otherwise damaged shells than do other lots. These shell characteristics, however, are sometimes found on shells that do not contain discolored seeds. In some instances the cotyledons beneath discolored seed coats are not discolored, but generally there is slight yellow or blue-black discoloration. A few cotyledons underneath discolored seed coats are conspicuously discolored.

The nitrogen and oil content of blue-damaged seeds and seed coats is not different from that of normal seeds. The discoloration apparently does not result in important changes in chemical constituent of the seeds. According to preliminary tests there is no detectable rancidity or off-flavor in blue-damaged seeds nor does the discoloration have any effect on germination of the seeds or vigor of seedlings.

Organism and Pathogenicity. Numerous unsuccessful attempts to isolate fungi from the discolored spots have been made. In rare instances *Sclerotium rolfsii* was isolated. It seems apparent, therefore, that the discoloration results from chemical reaction of pigments of the seed coat. Several facts were evident: *Sclerotium rolfsii* grew from a few of the discolored spots; it grew readily from shells which contained discolored seeds; it was known to be prevalent in fields in which Spanish peanuts were grown; and *S. rolfsii* secretes oxalic acid which diffuses into plant tissue in advance of hyphae. A test was made, therefore, in which crystals of oxalic acid were kept against nuts on living plants in damp soil for 72 hours. Typical blue damage resulted. Inoculation of peanuts with *S. rolfsii* resulted in the production of a considerable percentage of blue-black discolored seeds. Application of liquid from an autoclaved culture of *S. rolfsii* to green or partially cured nuts resulted in a lighter form of the discoloration. It seems evident, therefore, that the discoloration is an indicator reaction involving pigments of the seed coat and oxalic acid secreted by *S. rolfsii* growing in or on the peanut shells.

Most fields of Spanish peanuts in the southeastern United States are infested with *S. rolfsii*. When weather conditions or curing methods prevent the rapid drying out of the curing plants there may be continued growth of *S. rolfsii* from infested plants in the curing lot. Field studies show an interrelationship between curing methods, weather conditions, and development of blue damage. Prominent discoloration is not found in peanuts cured in stacks during hot, dry weather, but pronounced discoloration is found in peanuts cured in stacks during warm, damp weather. The blue-black discoloration does not develop in quick-cured peanuts taken from the same field as peanuts in which blue damage develops during slow curing in warm, damp weather. It is apparent, there-

fore, that the discoloration develops after peanuts are dug. Development of the discoloration in peanuts still in the soil or in peanuts in storage seems negligible.

Control. Considerable development of blue damage is reported from areas where field windrowing is used for curing peanuts. Absorption of moisture from soil and dew apparently promotes saprophytic growth of *Sclerotium rolfsii.*

Since weather conditions cannot be controlled and since rapid curing by artificial means is not a general practice, the best control measure at present is stack curing. If the peanuts are allowed to wilt before stacking, symmetrical stacks can be constructed that will facilitate curing.

STORAGE DISEASES—ROTS AND OTHER DISORDERS

Importance. Disorders developing in stored peanut fruits or seeds are of importance primarily to peanut brokers and processors. An occasional rotten or rancid seed may ruin a peanut product (169).

No information is available regarding the importance of storage diseases of peanuts to the peanut industry but personal conversations indicate that considerable loss sometimes is incurred.

Description. Of the disorders developing in stored peanuts, some are pathological and some are purely physiological. The pathological developments may have physiological end effects which obscure the initial pathological activity. Rancidity, for example, may develop from undetectable or incipient concealed damage, from visible rot, or from an independent enzymatic reaction within the embryo.

Table 4 lists the major storage disorders of peanut seeds, with probable initial causes.

Of these storage disorders, rots, rancidity and reduced vitality are more frequently encountered. Seed-coat discolorations and bleaching not accompanied by rot do not affect the use of the seeds for most processing or for seed stocks (49). Brittleness and sogginess in stored seeds may be accompanied by physiological changes of a detrimental nature, but this can not now be confirmed.

Blue damage and concealed damage undoubtedly can develop during storage of peanuts, but neither has yet been found developing to any considerable extent in storage (48, 49). Progress of concealed damage into seed rot during storage is probable also (48, 162), but has not been verified. Reduction in vitality of seeds during storage, the physiological activities involved, and the factors affecting these physiological activities are also suppositionary at present.

Organisms and factors involved. As discussed previously, a fungus flora develops in the peanut fruit in the soil (48, 161) and viable fungi are associated with peanut fruits and seeds after curing (48, 114, 162) and storage (44). These are primarily saprophytic fungi (44, 48, 114, 162) which may, under favorable conditions, produce rot or other seed damage.

The activity of fungi will be conditioned or limited by a number of factors. The most important of these factors appears to be temperature, moisture and time. Thus, rots, discolorations and fungus-produced rancidity and flavor changes which occur in storage will be influenced by

Table 4.—MAJOR STORAGE DISORDERS OF PEANUT SEEDS

Disorder	*Initial cause*	*Reference*
Concealed damage........	fungi	(48, 162)
Seed rots...............	fungi, bacteria	(170) and common observations
Blue damage...........	fungus	(49)
Other seed coat discolorations...........	fungi or enzymatic	Common observation
Seed coat bleaching.......	fungi or enzymatic	Common observation
Brittleness...............	low moisture	(170)
Sogginess...............	high moisture	(170)
Rancidity................	fungi, or bacteria or enzymatic	(162) (170)
Reduced vitality (germination)..........	fungi, enzymatic, etc.	Common observation

these same factors. Woodroof et al. (170) studied moisture content in relation to fungus development in stored peanuts. Their results indicate that unshelled, untreated, raw peanuts do not become evidently molded when stored at 6 per cent moisture or below, become slightly molded when stored at 6.5 to 7.5 percent moisture, and become pronouncedly molded at 10 percent moisture or above. For shelled peanuts the moisture content at which fungus development becomes evident and pronounced is slightly higher.

In this same study (170) the effect of relative humidity of the storage atmosphere plus time of storage on fungus development were tested. At 80 percent relative humidity fungus development was evident at 120 to 180 days and pronounced after 240 days. At 65 percent

and 50 percent relative humidity no pronounced fungus development was noted at the end of 360 days. It is indicated, indirectly, that peanuts stored at 80, 65 and 50 percent relative humidity will have moisture contents of approximately 10, 6.5 to 8, and 4 to 6 percent, respectively (170), and the effect of relative humidity on fungus growth must be through the moisture content of the seed.

Some rancidity developing in storage is not associated with fungus activity but the result of enzymatic action. This also appears to be conditioned by the factors of temperature, moisture and time. In the same study (170) rancidity was measured by means of organoleptic tests and peroxidase values. In general, rancidity developed along with or slightly earlier than evident fungus activity. Apparently no attempt was made to determine whether any rancidity developed independent of fungus activity. It was concluded, however, that "at 50 percent relative humidity storage life depends primarily on the development of oxidative rancidity or some other factor independent of moisture changes. . . ." Apparently at 50 percent relative humidity rancidity does not develop as soon as it does at 65 or 80 percent, but once beginning it develops more rapidly (170). This may mean that rancidity developing at 50 percent relative humidity is purely enzymatic in origin.

Brittleness and sogginess are primarily a matter of moisture lost or absorbed by the cotyledons. Brittleness develops when the moisture content falls below 4 percent and sogginess develops at moisture content above 10 percent. It may be assumed that the loss of viability of peanut seeds in storage will be closely correlated with fungus and enzymatic activity and thus conditioned by the same factors.

Control. Peanut brokers, in general, avoid storing peanuts with moisture content above 8 to 10 percent, but the study cited (170) recommends that the moisture content of stored peanuts should be held at about 5 percent with the storage atmosphere at about 60 percent relative humidity.

Present recommendations for control of storage diseases of peanuts may be summed up as follows:

A. Cure and dry the peanuts as thoroughly as possible before storage.
B. Control aeration in the storage area so that the relative humidity of the storage atmosphere is kept as low as possible.

PEANUT DISEASES OF MAJOR IMPORTANCE IN OTHER AREAS

Virus diseases, bacterial wilt, and rust—major diseases in some peanut-producing regions—have never been considered important in the United States. Both viroses and bacterial wilt appeared in the East Indies and spread to other regions. Virus diseases are of major importance in Africa; bacterial wilt is of major importance in the East Indies. Peanut rust is a disease of the West Indies, but has been reported from Africa and the United States.

VIRUS DISEASES OF PEANUTS

General

History. In 1907 a peanut "krauselkrankheit" (curl disease) was reported from Java (175). According to Storey and Bottomley (143) a similar or identical disease was noted in South Africa about 1909.

The name "rosette" was applied to the South African curl disease about 1925 (3, 143). Storey and Bottomley in 1925 (143) regarded rosette as definitely a virosis and transmitted the disease. Rosette was reported from equatorial Africa in 1926 (24), and was reported extensively from the African region thereafter. In 1945, rosette was noted as one of the three most important diseases of peanuts in Rhodesia, South Africa (64).

Virus diseases other than rosette have been reported from other areas. Mosaic was reported on peanuts in Argentina in 1936 (133) and in China in 1939 (174). In 1941 Costa (38) described a "ring spot" of peanut in Brazil as a virosis. KenKnight in 1941 (75) reported a transmittable virus disease, called "stunt," of peanuts in Texas. Jensen in 1948 (71) regarded virus diseases of peanuts as apparently unimportant in North Carolina but recognized the following: A leaf mottling (mosaic?) as a transmittable virosis; a ring spot as a fairly definite virosis; a rosette-like disease and a witches'-broom, both somewhat indefinite as to nature at present. Similar conclusions were later reached by Cooper (37), and most of these conditions have been reported from Australia (99). At present, then, there are only four described diseases of peanuts more or less definitely connected with viruses: Rosette, mosaic, ring spot, stunt.

There is considerable confusion as to the various viroses or probable viroses of peanuts. Several different conditions have been described as

probably due to the rosette virus (158). Typical mosaic conditions have been described from Africa (56) and the East Indies (175) as rosette, and yet mosaic has been reported by observers unwilling to regard it as a phase of rosette. In spite of this confusion, however, certain tentative conclusions may be reached, largely as a result of opinions expressed.

ROSETTE

Importance. Several reports include statements which may be used in evaluating the importance of the virus disease called "rosette." This information is condensed in table 5.

Table 5.—Estimates of Importance of Rosette

Year of report	*Area reported on*	*Observations on importance of rosette*	*Reference*
1907	East Indies	Serious loss	(175)
1945	South Africa	One of 3 most important diseases	(64)
1926	Gambia	78 percent infection, yield decrease 66 percent	(81)
1937	French West Africa	75 to 80 percent loss	(107)
1937	Ivory Coast	Vine weight loss 61 percent Pod weight loss 81 percent	(112)

Description. Rosette is characterized by a "condensation" of the plant. Petioles and internodes are shortened, giving the plant a typical rosette or clumped appearance. Storey and Bottomley in 1928 (144) gave a detailed description of peanut rosette as it was then recognized, and the following description is condensed from their report:

> The whole plant is severely stunted. Leaves, especially the younger ones, are more or less definitely chlorotic and faintly mottled. New leaves are pale yellow with dark green veins. Successive leaves are smaller, curled and distorted, uniformly yellow, and without green veins. These leaves usually turn green and eventually appear almost normal. Yield depends upon time of infection. If infection is early, small, sessil flowers which do not open may be formed, but they do not mature into fruits. If plants are infected after seeds begin forming low yields may be obtained. The disease is transmitted by grafting, is not seed-borne, or soil-borne.

An earlier observation indicated a general deterioration of infected

plants before the disease became visible. This would result in a reduced number of nuts with many seedless pods (24). Nuts, formed on rosetted plants, were also noted as having a lower shelling percentage (27).

It appears that at least two distinct types of symptoms, other than the typical, have been recognized and called rosette, and subtypes or variations of each in turn have been recognized and described. The following outline is based upon various published descriptions and the summary of Weiss (158).

VARIATIONS OF ROSETTE

(A) *Typical rosette* (Storey and Bottomley (144)).
(See description above)

(B) *Chlorotic rosette*

Variation 1. *Mosaic rosette:* Mottling of leaves, no marked yellowing. Less severe stunting or rosetting (Storey and Bottomley (144) and Hansford (56)).

Variation 2. *Yellows:* More pronounced chlorosis, very pronounced mosaic. No typical rosetting (Hansford (56)).

(C) *Nonchlorotic rosette.*

Variation 3. *Green rosette:* Leaves darker green than normal. No chlorosis (Hayes (59) and Porteres and Legleu (112)).

Variation 4. *Clump rosette:* Leaves normal green in color, rosette condition more pronounced than typical or other variations (Porteres and Legleu (112)).

Of these variations the mosaic type and the clump type are infrequent (56, 112), while typical rosette and yellows have been reported as having the greatest effect upon yield (56).

The Virus and pathogenicity. There are no indications that the virus (or viruses) associated with rosette has been isolated or otherwise studied. Weiss (158) recognized two acceptable technical names for the virus—*Arachis Virus* 1 or *Marmor arachidis.*

Peanut rosette has been transmitted by grafting (144) and by the legume aphid (135, 143). Later reports noted that the disease could not be transmitted to other legumes (141) nor could a rosette-type disease of a wild plant in the Congo be transmitted to peanuts (135). Weiss, however, lists a butterfly pea, *Centrosema plumeri* Benth. as another host of the virus (158).

The legume aphid, *Aphis leguminosae* Theob. is considered to be the vector of peanut rosette virus (135, 143). Other insects, which have been

suspected in regions where the legume aphid is rare, appear to have been eliminated from consideration.

Several factors seem to influence the pathogenicity of the rosette virus. These factors, obviously, may be effective on the peanut plant or on the aphid vector. The most important factors are:

(A) *Season.* In Africa late plantings are more severely attacked by rosette (24). Plants not infected during the first 8 weeks of the season apparently remain uninfected (25). Rosette has been reported more prevalent (27) and spreading more rapidly (24) in dry seasons.

(B) *Soil Moisture.* Possibly many of the apparent seasonal effects are actually effects of variations in soil moisture. An early report indicated a greater degree of susceptibility to rosette during a rainy period following a long drought (175). If there is scant rainfall in the first month of the growing season, rosette may be intensified (25).

(C) *Vegetative covering.* Certain observations indicate that denser vegetative coverings in peanut fields make for less severe rosette. Weeding does not prevent the spread of infection, but weed covering between peanut rows apparently results in reduced infection (27, 59, 135). Plants on the border of a field are reported most frequently infected (59). Whether these effects are independent of the effect of shading on soil moisture is not clear. Possibly there is some effect of these dense vegetative coverings on the vector.

Control. Some reports from Africa (25) have indicated that commonly grown varieties are susceptible. In the Gambia region, the Philippine pink, a local section from Tennessee red, is regarded as resistant (26) with the Philippine white either less resistant than the pink or not resistant at all (26).

From Gambia (6) and the Congo (7) it is reported that various control measures have reduced the incidence of rosette so that it is no longer serious. The following control measures have been recommended in addition to the use of resistant varieties:

(A) Seed treatment, insuring good stands and vigorous, drought-resistant plants (64).

(B) Early planting (142).

(C) Rotation—the disease is reported more severe the second season on the same land (135).

(D) Close planting for greater covering of soil surface (142).

(E) Roguing of volunteer peanuts (142).

(F) Roguing of infected plants (112).

(G) Spraying for control of vector (107).
(H) Grass mulching of soil (141).

BACTERIAL WILT—SLIME DISEASE

Importance. Bacterial wilt or "slime disease"[11], the first recorded important disease of peanuts, was observed in the East Indies around 1905 with losses of at least 25 percent (23). The disease was investigated extensively in the East Indies thereafter until 1937 when a gradual decrease in the importance of the disease was noted (154). Slime disease of peanuts was reported, without estimates of importance, from various regions and in South Africa the disease became of sufficient importance for an extensive study to be made in 1930 (87).

In the United States bacterial wilt of peanuts has generally been regarded as of minor importance. The disease was noted in North Carolina in 1912 when about 15 percent of Spanish peanuts on soil known to be infested were diseased (47). Wartime plant disease surveys (1944) reported some bacterial wilt of peanuts in the United States (13, 140). Experimental host range studies made in North Carolina in 1917 substantiated the general conclusion that the disease is relatively unimportant on peanuts in the United States since peanuts were placed in the "very slightly susceptible" class (131).

Description. As slime disease of peanuts was observed in the East Indies, attacked plants usually wilted rather suddenly with leaves on dead plants sometimes remaining green (23, 106). Slight, early infections, however, were usually overcome (106). Apparently the disease developed primarily in patches and general attacks over an entire field were very rare (23). In contrast to this are the descriptions given from the United States where the disease appears to be much milder (92, 136).

The attack of the causal organism is centered in the conducting cells of the roots and stems (23). One diagnostic characteristic is a large number of dead roots (106). Bacterial colonies form throughout the root, main stem and lower branches (23). These colonies are evident as streaks of brown or black discolorations (23, 106). The original point of entrance is possibly an insect wound or a lenticle (143). The infected tissue is finally blackened with extensive plugging and necrosis. If young plants are attacked the pods are invaded and remain small (106) or become wrinkled and develop a spongy decay (23). Shells of well-developed fruits have been found to contain the bacteria (106). When relatively

[11] "Slime disease" is a general term applied to the effects of *Bacterium solanacearum* on a large number of hosts.

mature plants are attacked there is no evidence of an invasion of the fruit (23).

When not otherwise evident the infection may be detected in cross sections of stems and roots. Dark-brown spots are usually evident in the cut xylem and pith regions (143) though healthy appearing plants may be filled with bacteria without any discoloration of the vessels (106).

Organism and pathogenicity. Since about 1911 *Bacterium solanacearum* (E.F.S.) E.F.S. has seemed definitely established as the pathogen of the bacterial wilt of peanuts. Inoculation tests have established that a typical slime disease is produced when peanuts are inoculated with *B. solanacearum* isolated from peanuts or other plants (87, 136). The nomenclature of the pathogen of slime disease is not definitely established, however, and it has been placed in four genera other than the genus *Bacterium.*

With a number of plants reportedly susceptible the existence of different strains of the bacterium seems likely. Early observations in the East Indies suggested the existence of a strain equally pathogenic to peanuts, tobacco and tomatoes (23, 122) and another strain more pathogenic to eggplant, potatoes and local species (122).

In the United States, *B. solanacearum* has been investigated most frequently in connection with the "Granville wilt" of tobacco, and bacterial wilt of peanuts was first noted on peanuts grown in rotation with tobacco (47). The bacterium from tobacco was successfully cross inoculated into peanuts. Further studies showed that numerous other species of cultivated plants and weeds are susceptible to the bacterium (131, 136). In South Africa cross-inoculation tests indicated that tomatoes and only one variety of tobacco were partially susceptible to the bacterium attacking peanuts (87). These results suggest the existence of different strains of the bacterium in the three widely separated peanut-producing areas, and this may explain the apparent unimportance of the slime disease of peanuts in the United States.

Factors most frequently suggested as affecting the pathogenicity of *B. solanacearum* on peanuts are soil type, soil moisture, and rotation practices. The virulence of the organism on peanuts in the East Indies was found to be higher on more moist soils, on heavy clay soils, and on soils planted to peanuts for several successive years (106). Continuous cultivation on irrigated soils resulted in an apparent increase in infections in dry seasons (121). In South Africa repeated cropping to peanuts increased the severity of the disease which was apparently restricted to the heavier loamy soils (87). This emphasis on soil texture and drainage sug-

gests that sandy soil may be an important factor in making bacterial wilt relatively unimportant in the United States.

Control. Planting of a resistant variety is the most convenient means of controlling the slime disease of peanuts. From selection work in the East Indies has come the variety "Schwarz 21" which appears to have considerable inherited resistance to the disease. In 1937 this variety was reported as resulting in considerable decrease in loss from bacterial wilt in that area (106).

A few attempts have been made to control *B. solanacearum* by soil treatment. Those treatments which might be applied to peanuts offer little hope (42, 110). Application of sulfur to East Indies soil gave no beneficial results on peanuts (42).

The control measures recommended in addition to the use of resistant varieties of peanuts are:

A. Seed treatment; the bacterium can be seed-borne (106).
B. Planting on light, well-drained soil (87, 106).
C. Rotation with crops which seem to be resistant to *B. solanacearum* such as sweet potatoes, grains and certain legumes (131).
D. Variation of the rotation to prevent building up other disease-producing organisms in the soil to the extent that the effects on peanuts will be more detrimental than that of *B. solanacearum.*

PEANUT RUST

Importance. Peanut rust, first described from Paraguay (28), apparently is distributed throughout South America (10). There are no direct indications of the past or present importance of peanut rust in South America, though Arthur (9) suggested that rust is sometimes a serious peanut disease there.

There is not complete agreement, but it is generally indicated that peanut rust is serious throughout the West Indies (104). Rust was first reported on peanuts in this area about 1911 (134) and the peanut crop was reported "devastated" by rust in the Dominican Republic in 1925 (36).

Rust of peanuts has been reported sporadically from Florida (28, 129). In 1941, KenKnight (74) reported peanut rust from Texas with seven fields of Spanish peanuts in one county infected.

Description. The existing literature is of little use in evolving a specific description for peanut rust. The symptoms, presumably, are typical for rusts with the pustules of the causal organism as the most useful diagnostic characteristic.

The peanut rust organism is found chiefly on the undersurface of leaves (10), where it appears, first, as necrotic flecks and later as yellowish spots on the upper surface. Spores form in typical sori rupturing the lower epidermis.

While these necrotic spots do not enlarge much, the infected leaves soon appear as though burned or scalded (74), and premature defoliation results (9). It is reported that premature ripening of fruits, and underdeveloped, shriveled seeds also result from rust infection (9).

Organism and pathogenicity. There is no agreement as to the proper name for the causal organism of peanut rust. Arthur, in 1925 (10) referred it to *Puccinia arachidis* Speg. as it was originally described.

According to Arthur (9) telia of this organism have been found only once. It may be presumed that this was in connection with the type specimen collection. Pycnia are unknown, and the organism does not have an aecial stage.

Peanut rust has no alternate host. The uredinial and telial stages are found on peanuts.

Although not cited specifically, it is presumed that the pathogenicity of this organism on peanuts has been proven by artificial inoculations. Arthur (10) lists *Arachis hypogaea* as the only host. West (159) discussing the rust in breeding plots in Florida reports it on *A. nambyquarae* Hoehne; *A. prostrata* Benth. and a hybrid of *A. hypogaea* X *A. nambyquarae.* KenKnight's report from Texas (74) indicates, indirectly, that selection and natural hybrids within *A. hypogaea* may sometimes be highly susceptible.

The organism appears to be seed-borne. It appears to have been brought into Florida recently on seeds from Brazil (159), although the rust had been reported from Florida twice previously (8, 129).

Some factors have been indicated as affecting the virulence of the organism. Arthur (9) concluded that peanut rust is more prevalent in wet seasons, with very little damage when infection is accomplished late in the growing season. In the West Indies the degree of infestation appears to depend largely on climate and condition of the soil (104). When conditions favor growth and vigor of peanuts only leaves approaching senility are infected. Under less favorable conditions infection is higher and results in death of the entire plant.

Control. Spraying with Bordeaux mixture has been reported as increasing the yield of rust-infected peanuts in the West Indies (104). In a 3-year experiment (104) it was finally concluded that while two applications of Bordeaux produced some beneficial results, it could not be said

that measurable control was achieved unless more than two sprays were applied. Arthur (9) regarded attempts to control the rust with Bordeaux sprays as "not achieving much success."

DISEASES OF APPARENT IMPORTANCE IN LOCALIZED AREAS

Three peanut diseases have been reported in recent years from definitely limited areas. It is indicated, directly or indirectly, that these diseases are of importance where found. It may be assumed that such diseases are a potential threat to other peanut producing regions.

1. *Sphaceloma scab* (Brazil)

A scab disease of peanuts caused by *Sphaceloma arachidis* Bitt. and Jenk. has been reported from Brazil with pathogenicity of the organism demonstrated (19). Species of *Sphaceloma* (*Elsinoe*) are associated with destructive anthracnoses of many plants.

The main symptom of this type of anthracnose is the small necrotic or hyperplastic lesions on leaves, hence the name "scab" for the disease. The lesions on peanuts are found predominantly on leaves, sometimes on petioles and stems (19). On leaves they are found on veins as well as between veins.

Sphaceloma scab was reported severe on peanuts in Brazil in 1938 with much less severe infection in 1939 and 1940 (39). Some varieties showed apparent resistance (39). No specific control measures have been recommended.

2. *Aspergillus crown rot* (Queensland, Australia)

A seedling blight or crown rot of peanuts has been described from Australia and an *Aspergillus* sp. is regarded as the pathogen (99, 100). The disease develops on plants from germination to maturity but is most important as it affects the initial stand since pre-emergence losses are greatest. Infection apparently takes place through lesions in the seed coat and spreads from cotyledons to the stem.

When plants approaching maturity are attacked, there is a general wilt. Sometimes a mass of spores of an *Aspergillus* sp. is found in this infected tissue. No inoculation tests appear to have been made, but it is assumed that this *Aspergillus* sp. is pathogenic.

Observations indicate that the disease is worse under conditions of high soil moisture, low fertility, unfavorable soil texture, and continuous cropping to peanuts. Recommendations for control are: Avoidance of excessive seed injury, seed treatment, planting of peanuts in rotation with corn, small grains, or grasses (99, 100).

Aspergillus rot is in part a pre-emergence disease and is most serious in that aspect. The post-emergence aspects of *Aspergillus* crown rot strongly resembles collar rot[12] of the southeastern United States.

3. *Texas Root Rot* (Southwestern United States)

In the southwestern United States *Phymatotrichum omnivorum* (Shear) Dugg. causes a root rot of a number of plants. This root rot is generally regarded as the most important plant disease in that area (31). Peanuts have been reported attacked by this organism in Texas, Arizona and New Mexico with greater losses on heavier soils. In one survey in a Texas county, 7 of 11 peanut fields were found infected with losses of at least 15 percent in most fields and up to 83 percent in some fields (75).

Fine, brownish strands of the fungus cover the roots of infected plants before above-ground symptoms are evident. Under moist conditions spore mats appear on the soil above infected roots. These mats are 2 to 12 inches in diameter, are originally white and cottony but turn tan with spore formation. The fungus forms rhizomorphs and pinhead size sclerotia. The sclerotia are light tan, and become darker and warty with age. The sclerotial stage has been called *Ozonium omnivorum* Shear. The foliar response is wilting, with death occurring in a few days. The entire root system decays and the plant slips from the soil easily.

It is suggested (75) that damage to peanuts by Texas root rot increased as a result of expanding peanut acreage to heavier soils as well as to soils known to be infected. Chester (31) suggests the following practices for the control of Texas root rot: (A) Three- or 4-year rotations of susceptible crops with highly resistant crops, such as grains; (B) avoidance of susceptible perennials, such as alfalfa, and certain trees and ornamentals; (C) promotion of soil organisms antagonistic to *Phymatotrichum omnivorum* through the use of manure or other organic fertilizers; (D) clean cultivation to eliminate susceptible weeds.

DISEASES OF MINOR IMPORTANCE

Quite a few diseases of peanuts appear to be unimportant wherever they occur. These diseases fall into two classes: (A) Diseases known to be of minor importance, and (B) diseases which cannot be definitely classified because they have not been extensively studied.

All of these diseases may be important under abnormal environmental conditions, thus such diseases should be regarded as potential threats.

[12] See page 269 for discussion of collar rot.

Phyllosticta Leafspot

In the southeastern United States primary and other seedling leaves of peanuts are always infected with a leaf-spot organism. The spots differ from typical peanut leafspot (*Cercospora* spp.) in being smaller, more irregular, without definite halos, and in being found only on juvenile leaves. Moist chamber culture of leaves shows that a *Phyllosticta* sp. is associated. This organism apparently cannot infest older leaves. It is also apparent that the peanut plant is not noticeably damaged by these leafspots on younger leaves. There is also a report from Burma of the occurrence of a *Phyllosticta* on peanuts (117).

Fusarium Wilt or Root Rot

Many peanut-disease surveys made in southern United States have listed *Fusarium* wilt on peanuts. In Texas a seedling blight, apparently due to a *Fusarium* sp., was regarded as one of several factors necessitating replanting of several fields in 1941 (75). In Georgia in 1932 (92) it was reported that an early or seedling wilt caused by *F. martii* var *Phaseoli* Burk. depleted stands from 10 to 38 percent in some counties. *Fusaria* can be isolated from peanut seeds readily and isolations from "diseased peanut tissue" in North Carolina were approximately 50 percent *Fusaria* (101).

In 1932 a *Fusarium* sp. was shown, by inoculation, to be the cause of a "destructive" wilt of peanut in Kenya, Africa (89), but since then continuous selection has maintained sufficiently high resistance to keep up production (65).

The following description of a *Fusarium* wilt of peanuts is based on that given by Miller and Harvey (92) from Georgia: Maximum infection occurs at blooming. Entire plant is usually killed, but sometimes only the shoots. Lesions on roots at first are small, elongate, light-centered with darker edges. Roots eventually are girdled by enlargement of lesions. Rot progresses through the roots with hyphae evident in the disintegrating tissue. There is no plugging of xylem vessels. In advanced stages the taproot is rotted just below soil surface.

The *Fusarium* "wilt" of peanuts, as described, is not a typical wilt. The plugging or disintegration of conducting cells usually found in wilts has not been reported from peanuts. Rather the peanut disease, as noted, was a typical root rot.

It is difficult to establish the pathogenicity of a *Fusarium* sp. The senior author has made numerous unsuccessful attempts to prove patho-

genicity of *Fusaria* isolated from diseased peanut roots and stems. Others have verbally reported similar results. Miller and Harvey (92), in Georgia, in tests on a *Fusarium* sp. from peanuts obtained results only with young plants and with abrasions on roots, and a filtrate of cultures also induced wilting in young peanuts.

The status of *Fusarium* wilt of peanuts is indefinite and its importance questionable. Though reported frequently from southern United States it has never again reached the proportionate importance attributed to it in Georgia in 1932 (92). The wilt in Kenya has apparently been brought under control by the use of selections (65). Further investigation, therefore, is needed to clarify the association of the *Fusaria* with peanut diseases. At present only seed treatment and good cultural practices can be recommended for control.

Sclerotinia Blights

Species of *Sclerotinia* have been reported as associated with stem, root and pod rots of peanuts (35, 85, 146). These diseases appear to be relatively unimportant and primarily of mycological interest.

According to Chu (35) and Suematu (146) two "new species" of *Sclerotinia (S. miyabeana* and *S. arachidis)* were described from peanuts in Japan by Hanzawa in 1911. Hanzawa's report was "privately printed" and mycologists have regarded the publication of these species as invalid.

According to Chu (35) the *Sclerotinia* blight of peanuts in Japan and China is primarily a stem rot, but all parts of the plant are sometimes attacked. Pods may be found containing sclerotia of the organism with seeds thinly coated with mycelium. Infection from spores is apparently through wounds except on flower petals, but hyphae from germinating sclerotia may invade uninjured tissue.

Lesions produced by *Sclerotinia miyabeana* are reported as purplish brown, eventually "shade-brown" while those produced by *S. arachidis* begin brown and blacken rapidly (35). Botrytis type conidia are frequently associated with the fungus called *S. arachidis* but have never been found associated with *S. miyabeana* (35).

Chu (35) reported several other hosts for these *Sclerotinias* including grasses, weeds and garden plants.

A "wilt" of peanuts apparently caused by *Sclerotinia trifoliorum* Eriks. was reported from Argentina in 1922 (85). *S. trifoliorum* is an important stem-rotting organism of clovers, but this apparently is the only report of it on peanuts. As control measures it was recommended that affected plants be destroyed and crop rotation and cultivation to prevent

excessive accumulations of soil moisture be practiced. There is the possibility that one (or both) of the *Sclerotinias* on peanuts reported from China and Japan is the same as this *Sclerotinia* reported from Argentina.

Botrytis Late Blight

Species of *Botrytis* have been observed associated with some unimportant diseases of peanuts. Possibly these *Botrytis* spp. are conidial forms of *Sclerotinias* but no studies have been made of this aspect.

Suematu (146) in Japan reported peanuts severely attacked by a *Botrytis* sp. during persistent wet weather, with the fungus forming conidia on stems and pods. Attacked pods did not mature and were later covered with dark sclerotia. Successful inoculation tests were reported.

Typical *Botrytis* late blight of peanuts has been observed by B. B. Higgins in Georgia[13]. Noted on mature or overmature peanuts, the infection develops during cool damp days of early fall. Growing tips were attacked and covered with a grey spore mass. Sclerotia were formed on pegs and pods, a few of which were partially to completely decayed.

It would appear that the parasitism of *Botrytis* sp. on peanuts may be dependent upon damp cool weather. Control methods include planting practices to avoid maturation during such weather.

Ashy Stem Blight and Diplodia Blight

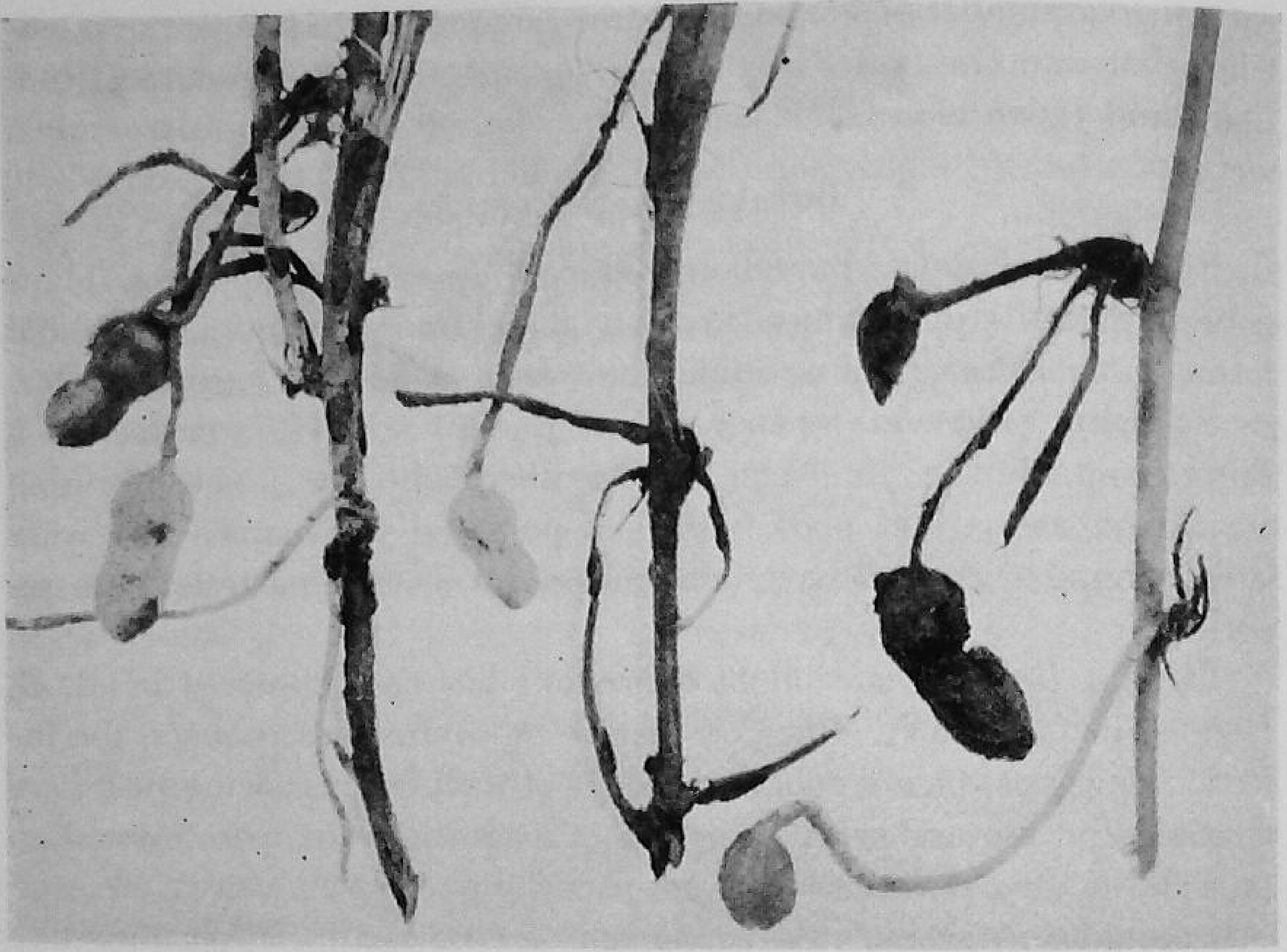
In the southeastern United States older peanut plants killed by *Sclerotium rolfsii,* insects, etc. are soon overgrown by fungi. Many living plants approaching maturity are similarly overgrown, particularly those partially defoliated by leafspot or insects. Examination usually shows that these fungal structures are sclerotia of *Sclerotium bataticola* Taub., pycnidia of *Macrophomina phaseoli* (Maubl.) Ashby, and pycnidia of a *Diplodia* sp.

Ashy stem blight. The sclerotia of *Sclerotium bataticola* and pycnidia of *Macrophomina phaseoli* on peanuts give the stems an "ashy" appearance. The structures are regarded as stages of the same fungus, and this has been demonstrated with isolations from plants other than peanuts (83).

Most references to *Sclerotium bataticola* on peanuts are primarily concerned with the seedling disease "charcoal rot"[14]. Observations on a variety of plants indicate that ashy stem blight results from invasion of

[13] Unpublished observations.

[14] See previous section on charcoal rot, page 267; also section on concealed damage, pp. 284-288 for another aspect of *S. bataticola* on peanuts.



Courtesy Georgia Agricultural Experiment Station

Figure 3.—Botrytis late blight on peanuts.

weakened plants. The organism, while sometimes a vigorous parasite on seedlings, particularly at high temperatures, appears to be primarily a weak parasite on older or mature plants. This parasitism of *S. bataticola* has been investigated and the various observations summarized (63).

In regard to peanuts, the ashy stem blight needs investigation. It is possible that following periods of excessively high temperatures, excessive defoliation, or excessive insect injury it becomes an important disease resulting in death or early maturity of many plants. This insect injury and defoliations may be prevented to some extent by dusting programs.

Diplodia blight. Diplodia sp. has been reported frequently on peanuts in the United States (13). It has been shown that *Diplodia* sp. is frequently associated with peanut seed[15] and thus may be seed-transmitted (149). A *Diplodia* sp. is frequently isolated from young peanut plants with collar rot[16] but pycnidia are generally not found on younger plants. Pycnidia are frequently found on stems of dead or living mature plants; thus *Diplodia* blight is distinctly a disease of older plants. *Diplodia* blight is easily confused with ashy stem blight. Frequently pycnidia of both

[15] See section on "concealed damage," pp. 284-288.
[16] See section on "collar rot," page 269.

Diplodia sp. and *Macrophomina phaseoli* are found on the same peanut plant.

Little is known about the parasitism of *Diplodia* sp. on peanuts. Lacking other conclusive evidence it may be assumed that *Diplodia* blight usually develops on nearly mature plants and results in little decrease in yield and few deaths. The inoculum is probably soilborne. There may be some carryover from seed-borne inoculum or seedling infection, but such early infected plants probably die before they reach the stage of maturity at which *Diplodia* blight develops.

Nematodes on Peanuts

Three types of nematodes have been reported on peanuts, but only the root-knot type has attracted much attention.

Root-knot nematodes. Root knot was reported from peanuts in the United States in 1931 (4) and 1943 (13), but only since 1946 has it been given more than passing attention. Parasitic nematodes were noted on peanuts in South Africa in 1926 (137) but apparently were considered unimportant.

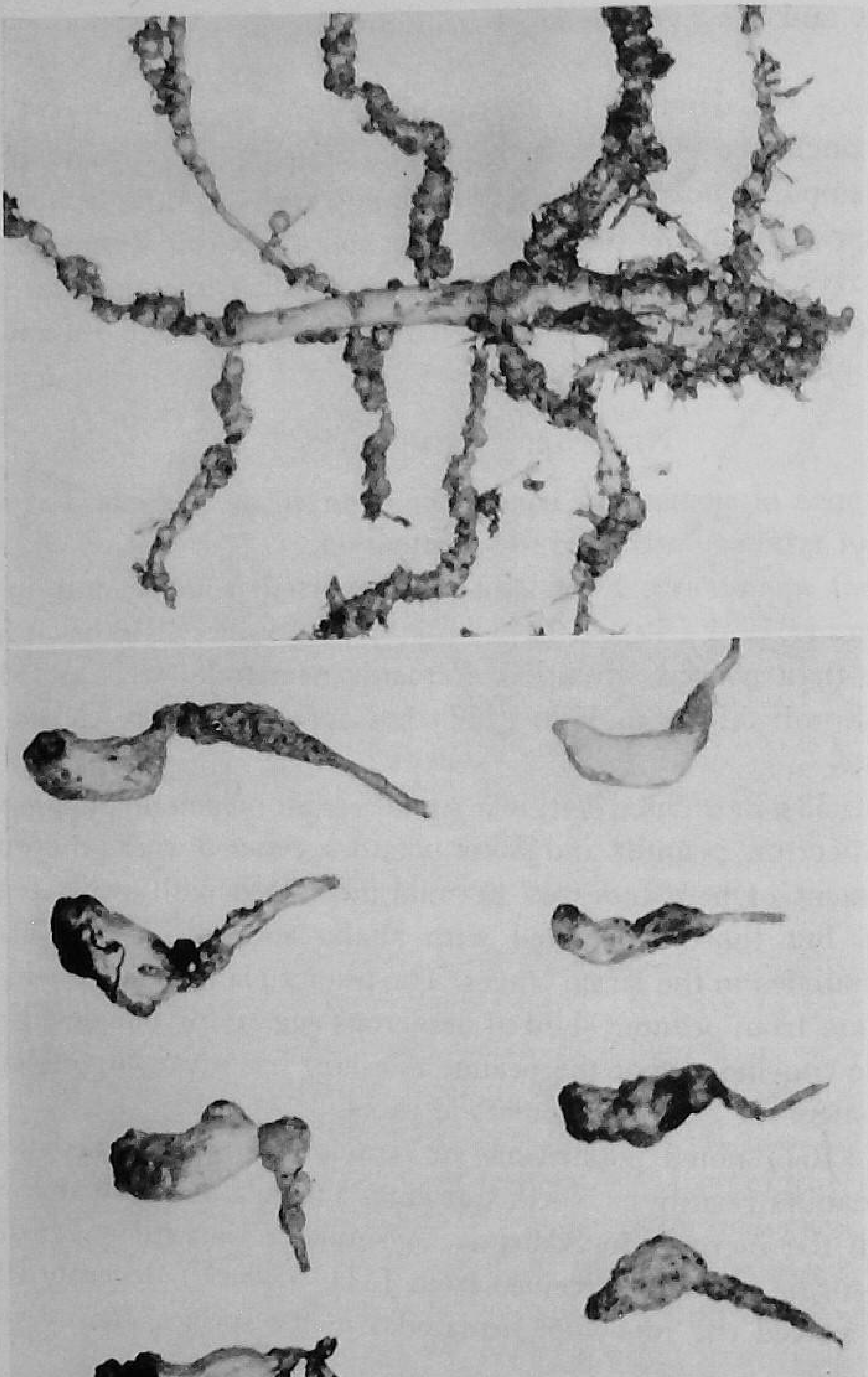
Christie (33) inoculated Virginia runners with nematode populations from alfalfa, cotton, peanuts and sweet potatoes. After 6 weeks there was no development of nematodes on peanuts inoculated with sweet potato populations, but those inoculated with alfalfa and cotton populations showed nematodes in the larval stages. The peanut plants inoculated with the population from peanuts showed numerous egg-laying females. From this Christie concluded that the peanut as a host has a varying effect on the development of different nematode races.

Wilson (164) noted populations or strains of root-knot nematodes attacking peanuts readily in North Carolina, Virginia and Alabama, and evidently on the increase in Alabama. A similar observation regarding southern Georgia has been received from J. H. Miller[17]. Recently Chitwood (32) placed the root-knot nematodes in the species *Meloidogyne arenaria*.

Root knot on peanuts is very similar to root knot on other plants. Typical galls are produced on the taproot, lateral roots, pegs and shells. The symptoms are shown in figure 4. If infection occurs early the plants are stunted and the margins of the leaves become necrotic.

Root knot does not seem to have been a serious disease of peanuts in the past. It looks as though the strain or strains of nematodes attacking peanuts are now on the increase in three major peanut-producing regions

[17] Personal communication.



Courtesy Alabama Agricultural Experiment Station

Figure 4.—Root-knot nematodes on runner peanuts.

of the United States. This disease, then, is a potentially serious disease in these regions. Rotation offers the only hope for large-scale control. There is need for research to determine host ranges of the strains attacking peanuts in order that rotation programs can be intiated.

Nematodes and witches'-brooms on peanuts. In 1935 peanuts were found in Tennessee with typical witches'-brooms and the nematode *Cephalobus elongatus* de Man. was isolated from them (5). In 1936 a similar witches'-broom of peanuts was found in Texas. Isolations yielded *C. elongatus* and *Acrobeles crossatus* Steiner. In the latter case it was doubted that either nematode was the cause of the witches'-broom.

Meadow nematodes and peanuts. Nematodes of the genus *Pratylenchus* Filipjev cause a general root destruction of many plants (138). Little is known of the effects of these meadow nematodes on peanut roots, but they do frequently attack pods, producing black spots and providing points of entrance for secondary invaders. Steiner (138) has indicated need for more work on these nematodes. This need is doubly evident for peanuts because of the possibility of both root and fruit damage.

Rhizoctonia on Older Peanuts

There are references from almost all peanut-producing regions to *Rhizoctonia solani* Kuhn on peanuts[18]. While usually not stated, it appears that the primary concern is with seedling diseases.

In the southeastern United States many peanut plants beyond the seedling stage show typical dry, greyish or reddish-brown *Rhizoctonia* cankers on stems near the soil. Although some cankered stems break off in wind or during cultivation or dusting, few, if any, plants appear to be killed as a result of this cankering. At maturity numerous greyish-blue fruiting bodies on the "perfect" stage—*Corticium solani* (Prill. and De.) Bound and Galz.—may be found on peanut stems in contact with the soil. It may be that high temperatures during the growing season are the important factor in making *R. solani* of little apparent consequence on peanuts beyond the seedling stage.

Possibly attacks of *R. solani* on the peg are an important factor in harvest nut losses[19]. At present any theory as to *R. solani* and diseases of peanuts beyond the seedling stage is purely suppositionary.

[18] See page 267 for section on seedling dry rot.
[19] See page 282 for section on soil rots of nuts and pegs.

DEPREDATIONS OF ANIMALS

Animals may damage peanut plants in any stage from the planted seed to the mature plant. These depredations may be evident in forms other than the eating of leaves, seeds or nuts. The damage to the peanut crop caused by animals eating the mature or almost mature pods is sometimes quite spectacular.

Gophers (tortoises) have been noted from Florida (119) as pests of peanuts, and the western gopher (a rodent) was similarly noted from Oklahoma (77). Everyone has observed considerable numbers of dead plants following attacks of moles on the root system. Skunks and wild turkeys display a fondness for peanut pods in the "milk" stage. There is nothing, however, which will indicate that any general importance can be attached to such depredation of animals.

PHYSIOLOGICAL OR NONPATHOGENIC DISEASES OF PEANUTS

Mineral Deficiency Symptoms. The chart on next page summarizes the known mineral-deficiency symptoms on peanuts.

Described Physiogenic Disorders. The following have been specifically reported as nonpathogenic diseases of peanuts:

"Clump" or "Bunch". A condition called "clump" or "bunch" has been described from India. Plants were densely clumped, with tufted and dwarf shoots, yellowed leaves, arrested growth and erect habit. Yield of affected plants was reported (147) as only 30 percent of normal. Poor soil and the use of immature seeds were thought to be responsible. No evidence of parasitism was noted. It has been suggested that "clump" may be a phase of rosette but the matter is still indefinite.

Nonparasitic Leafspots. A peanut leafspot characterized by somewhat rectangular, brown to black splotches on the lower surface, with pin-point necrotic areas was described from Georgia in 1941 (69). The disorder, found on puddled clay soil, was believed to be a mineral deficiency resulting from the puddling.

Inherited Albinism. Albinism, varying from a few chlorotic streaks in leaves to complete albinism of the entire plant, is a fairly common occurrence in peanut fields in southern United States. This albinism has not been studied. The only logical explanation seems to be that it is a genetical condition resulting from chance cross pollination.

Pale Dwarf. A condition called "pale dwarf" reported from Java in 1927 (58) was characterized by early paling and dwarfing of leaves. The

MINERAL-DEFICIENCY SYMPTOMS OBSERVED ON PEANUTS

Deficient Mineral	*Peanut Variety*	*Age of Plants*	*Foliar Symptoms*		*Reference*
			Leaves	*Stems*	
Nitrogen	Virginia Bunch	6 weeks	General chlorosis	Reddish color	(29)
Phosphate	Virginia Bunch	6 weeks	Fully developed leaves are dark green changing to yellow	Reddish color	(29)
Potassium	Virginia Bunch	6 weeks	Light green changing to scorch areas on margin	Reddish color	(29)
Calcium	Virginia Bunch	6 weeks	Brownish necrotic areas on fully developed leaves over entire surface	Disturbances in meristematic region in late stages of deficiency	(29)
Magnesium	Virginia Bunch	6 weeks	First in older leaves a chlorosis of leaf margins, with entire leaves becoming chlorotic	Lack of the red coloration	(29)
Iron	Spanish	6 weeks	Youngest leaves become chlorotic		(132)
Boron	Virginia Bunch	6 weeks	Brownish necrotic areas limited to the edges of the leaves		(29)
Zinc	Spanish	all stages	No observed symptoms	No observed symptoms	(14)
Manganese	Spanish	all stages	No observed symptoms	No observed symptoms	(132)
Copper	Spanish	all stages	No observed symptoms	No observed symptoms	(132)
Sulfur	(No reports in the literature)				

Prepared by H. S. Ward, Jr., associate botanist, Alabama Polytechnic Institute, and through his courtesy.

peanuts usually recovered. The condition was believed to be nonparasitic and caused by excessive heat of surface soil after planting.

Physiological Chlorosis. Chlorosis, apparently neither inherited albinism or associated with viroses, has been reported from Somaliland (18) and attributed to unfavorable weather and soil conditions. A similar chlorosis has been reported from Texas as "physiological chlorosis" (75).

Disease-Like Results of Insects. Certain effects of insects on plants are sometimes difficult to distinguish from pathogenic diseases. An example is "peanut pouts" originally regarded as a disease of unknown cause. The swollen, distorted areas on leaves and young stems were shown by Metcalf (90) to be the result of toxins from mass-attacking leafhoppers. It was later pointed out that thrips injury is also sometimes referred to as peanut pouts (128).

RARE OR ACCIDENTAL DISEASES

Any crop is sometimes found attacked by fungi under "unusual" circumstances. It is rare that such unusual diseases assume any importance, and they have never been regarded as important on peanuts. Only a few diseases of this type have attracted sufficient attention to be reported.

1. *Seedling rots caused by mold-type fungi.* Seedlings of peanuts are sometimes killed by overgrowth of mold fungi (72). Almost always extenuating circumstances are obvious: The seedling has been suppressed or wounded by growing under a hard soil crust; there has been excessively heavy rainfall coupled with excessively low temperatures; or some other equally apparent circumstance. The fungus overgrowth is usually a *Rhizopus* sp., *Penicillium* sp., or *Aspergillus* sp.

2. *Fungus leafspots following insect injury.* Typical fungus-type leaf spotting sometimes develops following insect injury. For example, an *Alternaria* sp. leafspot has been reported from Virginia (11) associated with leaf-hopper damage. Undoubtedly these unusual leafspots are very unimportant in the total picture of peanut diseases.

3. *Diaporthe blight.* A situation has been reported from Virginia (12) in which *Diaporthe phaseolorum* var. *sojae* (Lehm.) Wehm. was suspected as the initial cause of the death of peanuts. In a later study (84) neither the species *D. phaseolorum* (C. and E.) Sacc. nor the variety could be shown by inoculation to be pathogenic to peanuts.

4. *Anthracnose of peanuts.* There are only two reports on the occurrence of anthracnose fungi on peanuts. A *Colletotrichum* sp. was observed on peanut leaves in Uganda, Africa, in 1926 (130) and *Colletotrichum* sp. was the most abundant fungus in a few dark-colored stem lesions on peanuts in Oklahoma in 1944 (78).

MISCELLANEOUS FUNGI

A large number of fungi have been reported from peanuts only once and the reports are now buried in obscurity. Host indexes list species of fungi on peanuts for which it is impossible or almost impossible to find the

original reference. Abstracting journals also note many fungi as "on peanuts." These fungi, which do not seem to be associated with important peanut disorders, are best classified as "miscellaneous." To make a detailed listing of such fungi would probably confuse rather than clarify. The reports on miscellaneous fungi of peanuts fall into three main classes:

(A) Saprophytic fungi included in results of general mycological surveys.

(B) Fungi suspected of being parasitic on peanuts but which have not yet merited or received further investigation. Examples of this would be the *Phoma* sp. noted on rotting peanut stems in Alabama in 1914 (168) and the *Verticillium* sp. found in wilting peanuts in Australia in 1945 (99).

(C) Fungi described as new species. For example: *Ascochyta arachidis* Woron. listed on "dying peanut leaves" in the Caucasus in 1924 (173).

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